ELECTRICAL ENGINEERING

SEPTEMBER 1944

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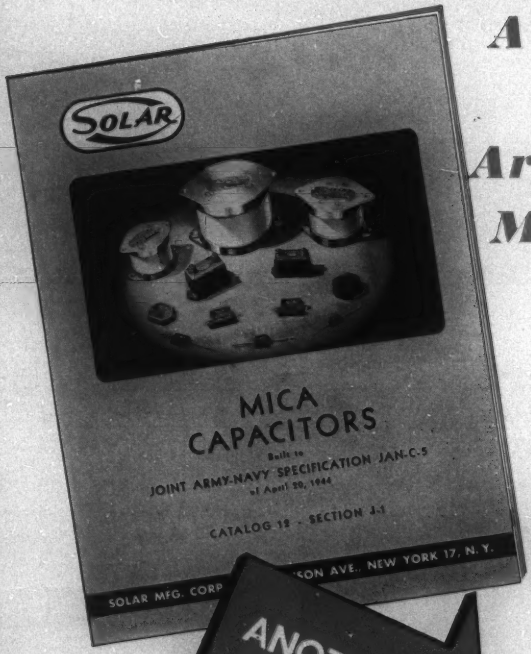

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FREE { THE KEY TO THE WORLD'S BIGGEST GLASS RESEARCH LABORATORY!

WE mean it. The services of the world's largest glass research laboratory are yours for the asking. In its 75 years, Corning has developed more than 25,000 different glass formulae . . . a vast storehouse of glass-making research and skill ready and able to help you no matter what your problem.

At Corning, right now, more than 250 planners, researchers, engineers and production men are constantly at work to make better glass for the radio tubes, X-ray bulbs, cathode ray tubes, resistor tubes and other glassware you need in your business. As a result, it is difficult to find *any* electronic glassware in use today that did not get its start at Corning.

Actually, many of Corning's developments come properly under the head of "near miracles". It was only yesterday, for instance, that it became practical to solder metal to glass. But Corning Research did it. And today the Corning metallized bushing is performing an important job in the electronic equipment of the industry's leading manufacturers . . . a proven time and money saver. And we could quote a dozen other examples just as good.

If you'd like to know more about what Corning knows about electronic glassware, we have a suggestion. Write today for a new booklet, "There Will Be More Glass Parts in Postwar Electronic Products". Please address the Electronic Sales Dept., N-9 Bulb and Tubing Division, Corning Glass Works, Corning, New York.

CORNING *means* Research in Glass

Electronic Glassware

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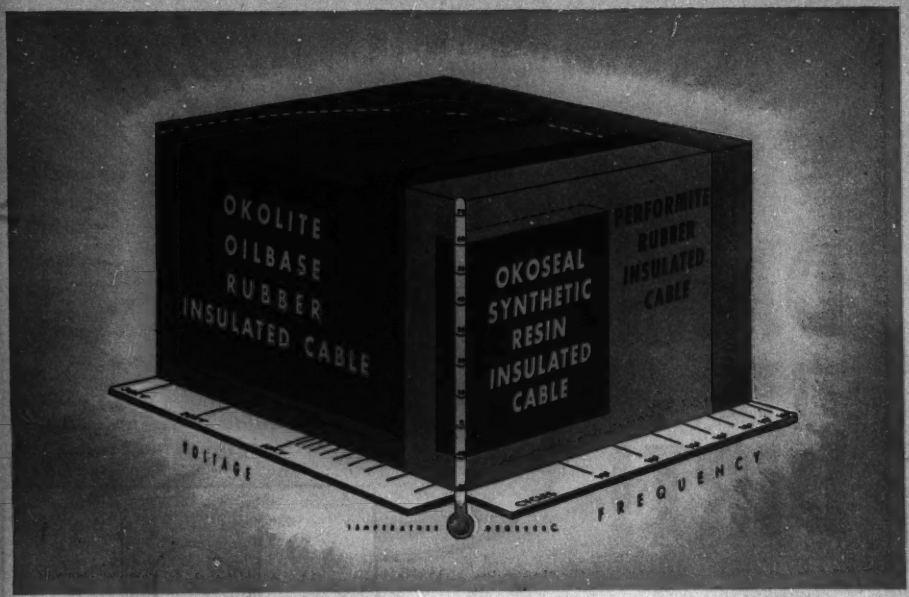


PERSPECTIVE: Selecting Insulated Cable Requires a Multi-Dimensional Approach

This 3-dimensional graph illustrates practical fields of usefulness of 4 widely-used types of cable insulation. Each type has particular characteristics that make it suitable for definite applications — but at the same time each possesses certain limitations.

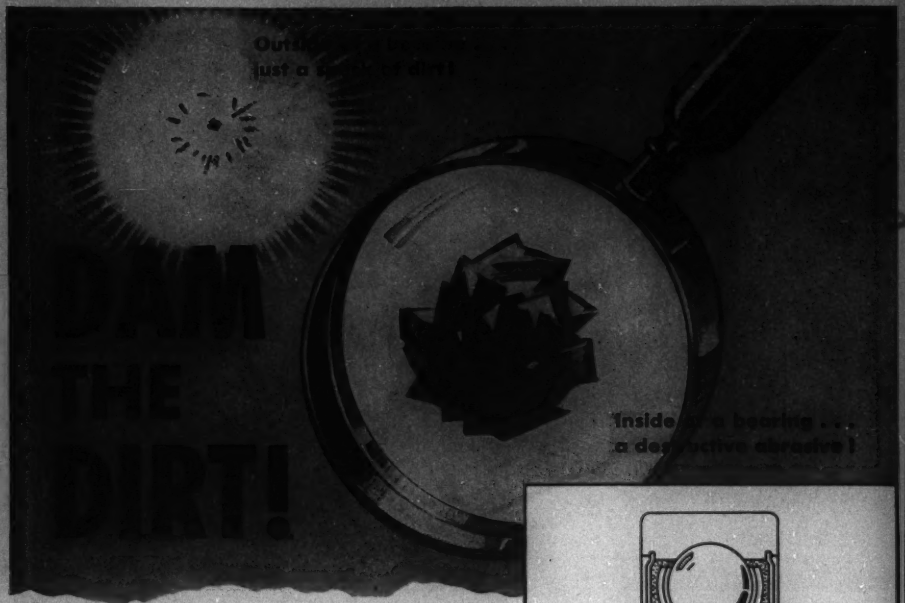
The pictured values show the present maximum voltage, frequency and temperature limits for which these four insulations are commonly used. The insulations with the higher values can, in many cases, be used as alternatives for those having lower values.

Design engineers may find this rather unusual graph helpful in selecting a cable for some specific application. The problem, however, is not always as simple as indicated because it is often necessary to obtain cables having additional characteristics not covered by this graph — such as resistance to moisture, oil, chemicals, flame, etc.

Actually there are available many other insulations developed through Okonite Research — such as glass, paper, cambric, rubber and many synthetics — that cover the full range of electrical applications. Through intensive laboratory and long field experience, our engineers have acquired the over-all perspective that can help you select the *one* cable best suited for your purposes from *every* angle. Just outline your problem and let us make recommendations. The Okonite Company, Passaic, New Jersey.

OKONITE

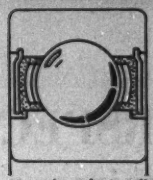
INSULATED WIRES AND CABLES



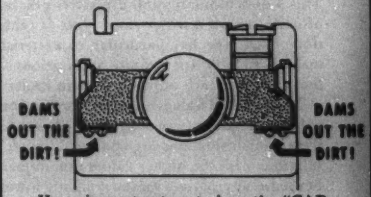
Dirt is the curse of every user of motors and machines. In shop and factory it gets into the average bearing, where it destroys the high finish, abrades the polished surfaces, creates friction that results in vibration, looseness and noise. And its action is cumulative—once started, it leads to premature bearing failure.

In the NORMA-HOFFMANN "CARTRIDGE" BALL BEARING, wearless metal seals combine with "labyrinth" grease grooves to form a highly effective barrier that dams out dirt—at the same time preventing the escape of the lubricant packed in the extra large grease reservoir afforded by the double-row width of the bearing. As a result, the initial high anti-friction efficiency of the "CARTRIDGE" BEARING is maintained over extremely long periods.

NOTE:—Many representative motor, machine and tool builders are incorporating the "CARTRIDGE" BEARING in their products. When you buy such units, ask for the NORMA-HOFFMANN "CARTRIDGE" BALL BEARING.



This shows a section of an ordinary single-row "shielded" ball bearing, with its space restrictions limiting the grease capacity and the effectiveness of the sealing devices.



Here, in contrast, note how the "CARTRIDGE" BEARING double-row width not only affords at least 100% larger grease capacity than the ordinary single-row "shielded" bearing, but also permits the use of a highly effective and wearless seal.

NORMA-HOFFMANN

"CARTRIDGE"

BALL BEARING

NORMA-HOFFMANN BEARINGS CORPORATION, STAMFORD, CONN. FOUNDED 1911

TO WIN THE WAR: WORK—FIGHT—BUY WAR SAVINGS BONDS!

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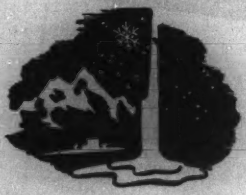

Dow Corning Fluids possess unique characteristics that warrant their close study by technicians in varied industries—especially those engaged in the current war effort. These water-white permanent liquids are furnished in two series, covering a wide range of viscosities.

Dow Corning FLUIDS

Dow Corning Silicone Products Include:

RESINS—High temperature insulating varnishes for use with heat stable electrical insulating materials.

GREASES—For lubrication of valves in high temperature or corrosive chemical services. Plug Cock Grease—for metal valves. Stopcock Grease—for glass and ceramic valves.

Summary of Characteristics

- Remarkably low viscosity change from sub-zero to high temperatures.
- Exceptionally inert to metals, rubber and plastics.
- Unusually resistant to chemicals and high temperatures.
- Effective water repellent.
- Lubricant for glass, ceramics, plastics.

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"Gas Cushion" makes life easier

In Type PC Pressure-Compensated Cable, a gas cushion provided by one or more small tubes included in the impregnated fillers, stabilizes operating pressures within fixed limits. The schematic diagram above shows clearly how it functions.

The helical tubes, perforated at intervals of about four times the length of lay, are filled with dry nitrogen gas. During manufacture, some of the insulating compound is forced into the perforations.

After the cable is installed, slugs of the compound gradually collect in the low portions of the tubes and the gas collects in the domes.

As the cable heats up under load, the compound expands and additional compound is forced into the tubes. The gas trapped between the slugs is compressed and thus acts as a cushion to prevent development of internal pressures which would ordinarily stretch the lead sheath.

In this way, points of concentrated pressure are avoided. Pressure remains uniform and evenly distributed along the entire cable.

When the cable cools, the oil saturant contracts and the compressed gas forces the excess oil back into the cable, thus preventing wide swings from pressure to vacuum.

. . . in NEW paper insulated power cable

IN a paper insulated cable of the conventional "solid" type, expansion of the lead sheath followed by contraction of the insulation under the thermal cycles of normal operation brings about the formation of voids inside the cable. The resulting ionization discharges within the voids cause rapid deterioration of both paper and insulating compound.

Type PC Pressure-Compensated Cable prevents formation of such voids; and does it without any radical change in basic construction, without highly special accessories, without complicated methods of installation and without high maintenance expense. Type PC Cable offers, in effect, a conventional cable —with the addition of a simple pressure-compensating gas cushion which holds the internal operating pressures within fixed limits.

A bulletin on PC Cable is available. Send for your copy.

TYPE PC PRESSURE COMPENSATED CABLE

AMERICAN STEEL & WIRE COMPANY

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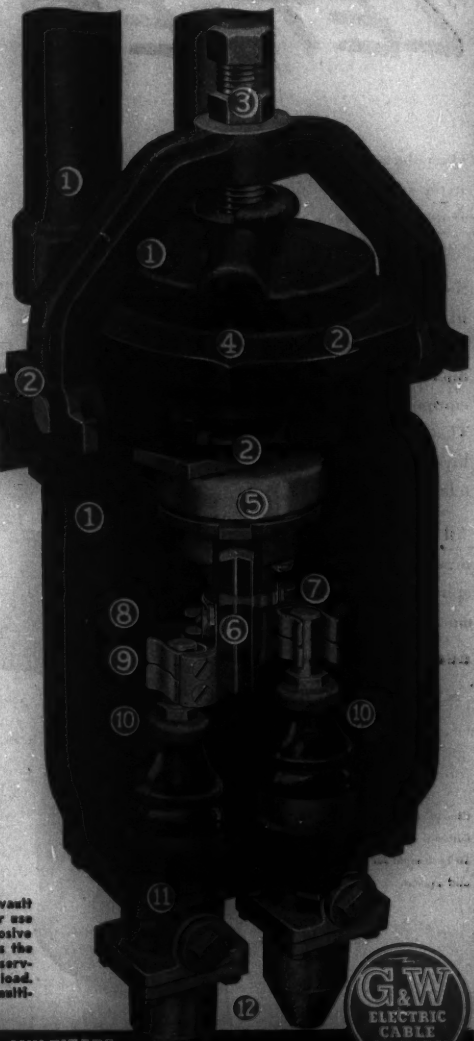
✓ *Check these design features — for the reasons Why* G&W TYPE "FC" OIL FUSE CUTOUTS

prevent cable & equipment trouble due to overloads and short circuits . . . protect men against accidents



1. Steel tank, cover, cover clamp and expansion chamber.
2. Cover and cover clamp interlocked, preventing withdrawal or insertion of fuse carrier except in the "OFF" position. Safety in fuse replacement is assured.
3. Large screw and locknut in cover clamp insures perfectly tight gasketed joint between cover and tank.
4. Cover easily switched OFF and ON by means of a rod, very simple to adapt for gang-operation.
5. The higher voltage ratings have porcelain insert between fuse chamber and cover.
6. Short circuits quietly and definitely cleared in ½ cycle. #FC42 interrupts 25000 Kva at 60 cycles, single phase.
7. Simple inexpensive fuse link, easily replaced.
8. All live contacts are well below the oil level and the oil level is not critical.
9. Beryllium copper spring contacts carry current without excess heating and provide ideal switching contacts.
10. Unit detachable compound filled potheads with closed hoodnuts definitely seal cables and prevent migration of oil from tank. They protect cable ends against surges.
11. The Resistoyl gasketed joints at the bottom of the tank are easily made permanently oil-tight.
12. The bottom location of potheads reduces the wall space to a minimum and provides for logical cable training. Overhead and subway style cable entrances are interchangeable.

G & W Type "FC" Oil Fuse Cutouts are used in subway, vault and overhead installations. They are especially suitable for use in locations which are exposed to corrosive fumes, explosive gases, salt air and inflammable dust. Their main purpose is the protection of transformers, branch circuits and industrial services. They are also used for sectionalizing circuits under load. With the simple gang-operating mechanism they serve as multi-pole oil switches. 5000 volts, 200 amperes.

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OIL FUSE CUTOUTS . SUBWAY OIL DISCONNECTS & SWITCHES

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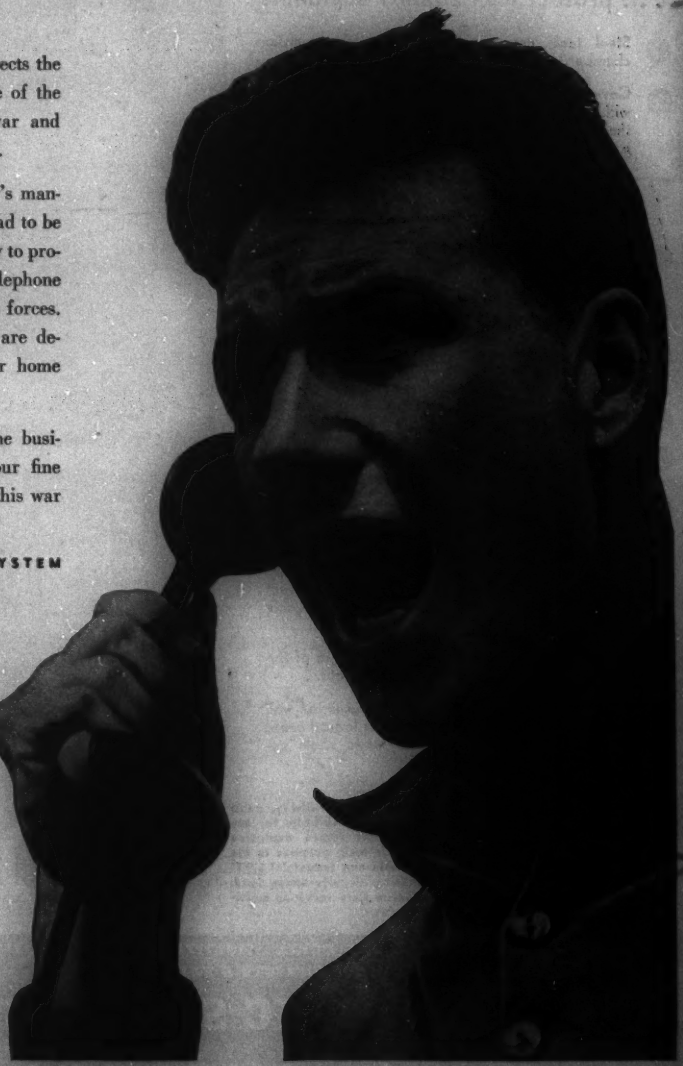
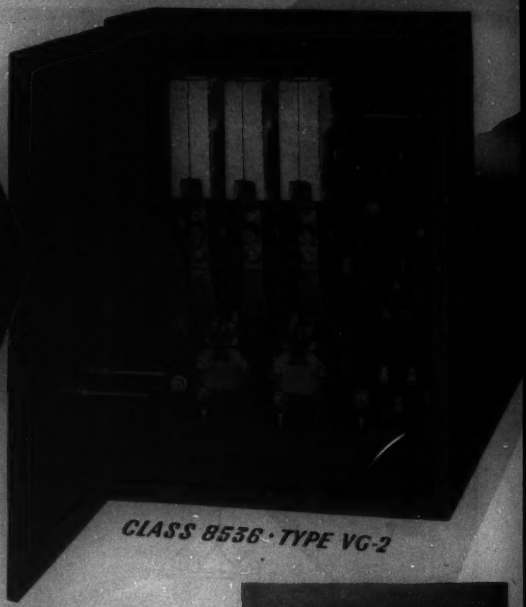
Please try to keep the Long Distance circuits clear from 7 to 10 each night for the service men and women.



The big guns start booming when the section chief of a cannon company gives the order to "fire"

AN *Improved* SIZE 4 STARTER WITH FIVE NEW FEATURES



CLASS 8536 · TYPE VG-2

---SMALLER-QUIETER-----

1. Improved blow-out coils have fewer turns and are wound with heavier copper—assuring less heating effect, and efficient interruption of stalled rotor currents for electric motors up to 100 horsepower.
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4. New shading coil affords exceptional mechanical strength. This coil is held in place by the magnet coil in such a manner as to prevent its falling out. Use of heavy brass ribbon makes shading coil virtually unbreakable.
5. Narrower panel saves space and flat door cabinet permits gang mounting.

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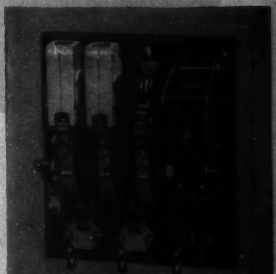
This greatly improved Type V device is available in a complete range of enclosures for all Size 4 starter applications, including reversing, combination, multi-speed, reduced voltage, etc. Call in or write your nearest Square D Field Engineer for complete information.



Open type starter panel with one arc chute removed to reveal contacts and blowout coil.

Side view of panel showing "E" type magnet, floating armature and new shading coil.

ELECTRICAL EQUIPMENT • KOLLSMAN AIRCRAFT INSTRUMENTS

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The name "U.S. ROYAL" has long been reserved by this Company for rubber products of exceptional quality.

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Now comes a new development in rubber technology, greatly speeded by critical war-time needs... a new insulation material, "Safety-Tested" for every desired quality. This has been successfully embodied in the new line of U.S. ROYAL CORDS and CABLES... a line that offers to the electrical industry the assurance of long, economical, trouble-free service... a line truly worthy of the name "Royal".

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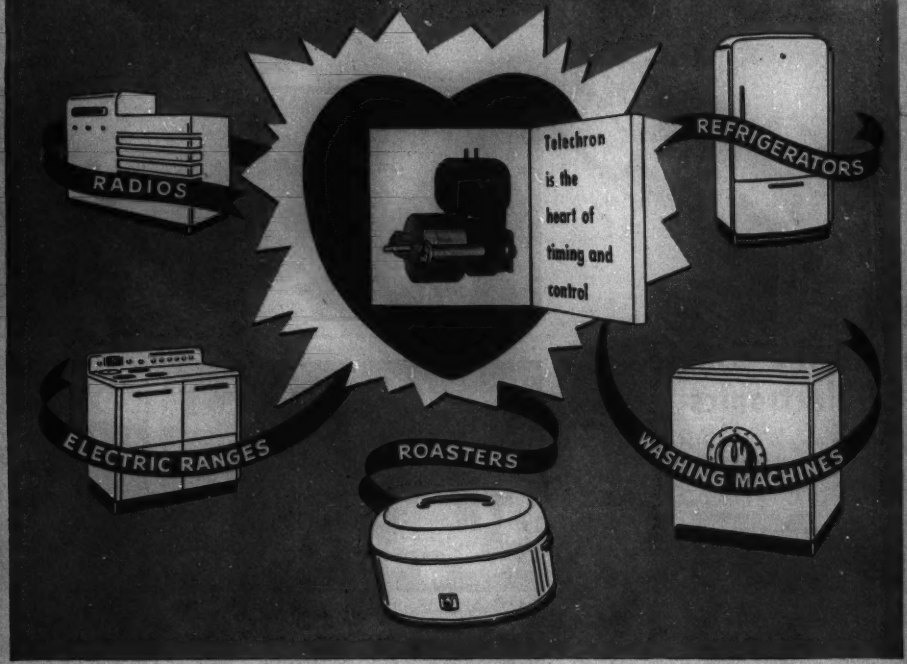
will time and control post-war home appliances



AUTOMATIC timing control for ranges, washing machines, dishwashers, roasters and clothes driers — automatic time control and station selection for radios — automatic defrosters for refrigerators — *these will be important sales features for new appliances now being designed for post-war production.* . . . For more than 25 years, Telechron electric motors have stood for dependability in automatic timing and control. They are adaptable to all kinds of uses in home appliances. Write Dept. G, Motor Advisory Service.

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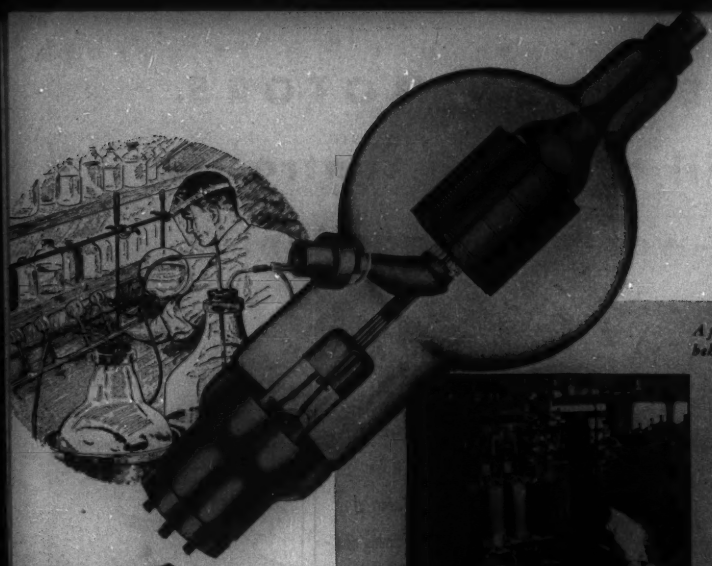

the *Science* behind the science of electronics

The pattern of progress in the science of electronics is determined by the achievements in creating and developing new and more efficient electron vacuum tubes. Therefore, the whole complex task of vacuum tube development — involving the intelligent application of many sciences — comprises the real science behind the science of electronics.

To create and produce the modern vacuum tube requires experience and skill of the highest order in these many sciences in addition to complete facilities for their application. The list includes everything from chemistry and metallurgy — the technology of glass fabrication and vacuum pumping — to physics, optics, thermo-dynamics and most important of all — Electronics.

The resources and resourcefulness of Eimac laboratories have accounted for many outstanding contributions to the science of Electronics. A fact which is attested to by the leadership which Eimac tubes enjoy throughout the world. These comprehensive facilities are continuously being utilized to achieve better and better results for the users of Eimac tubes.

Eimac Engineering is devoted solely to the development and production of electron vacuum tubes. However, since the electron vacuum tube is the heart of all electronic devices it is advisable for users and prospective users of electronics to look first to the vacuum tubes required. A note outlining your problem will bring advice and assistance without cost or obligation.

• • •

Write for your copy of Electronic Telesis — a 64 page booklet fully illustrated — covering fundamentals of Electronics and many of its important applications. Written in layman's language.

A few of the branches of the Science behind the Science of Electronics

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METALLURGY—*Spectrographic Analysis of the Rare Metals Used in Vacuum Tubes*

VACUUM TECHNOLOGY—*Constant Research to Develop Better Vacuum Techniques*

PHYSICS—*Actually Viewing Emission of Electrons with Electron Microscope*

ELECTRONICS—*Determining Factors which will Determine Data on Vacuum Tube Capabilities*

OPTICS—*Studying the Effect Processing has on the Structure of Materials Through Photomicrography*

GLASS TECHNOLOGY—*Skilled Assignment and Technique to Produce Complicated Glass Structures*

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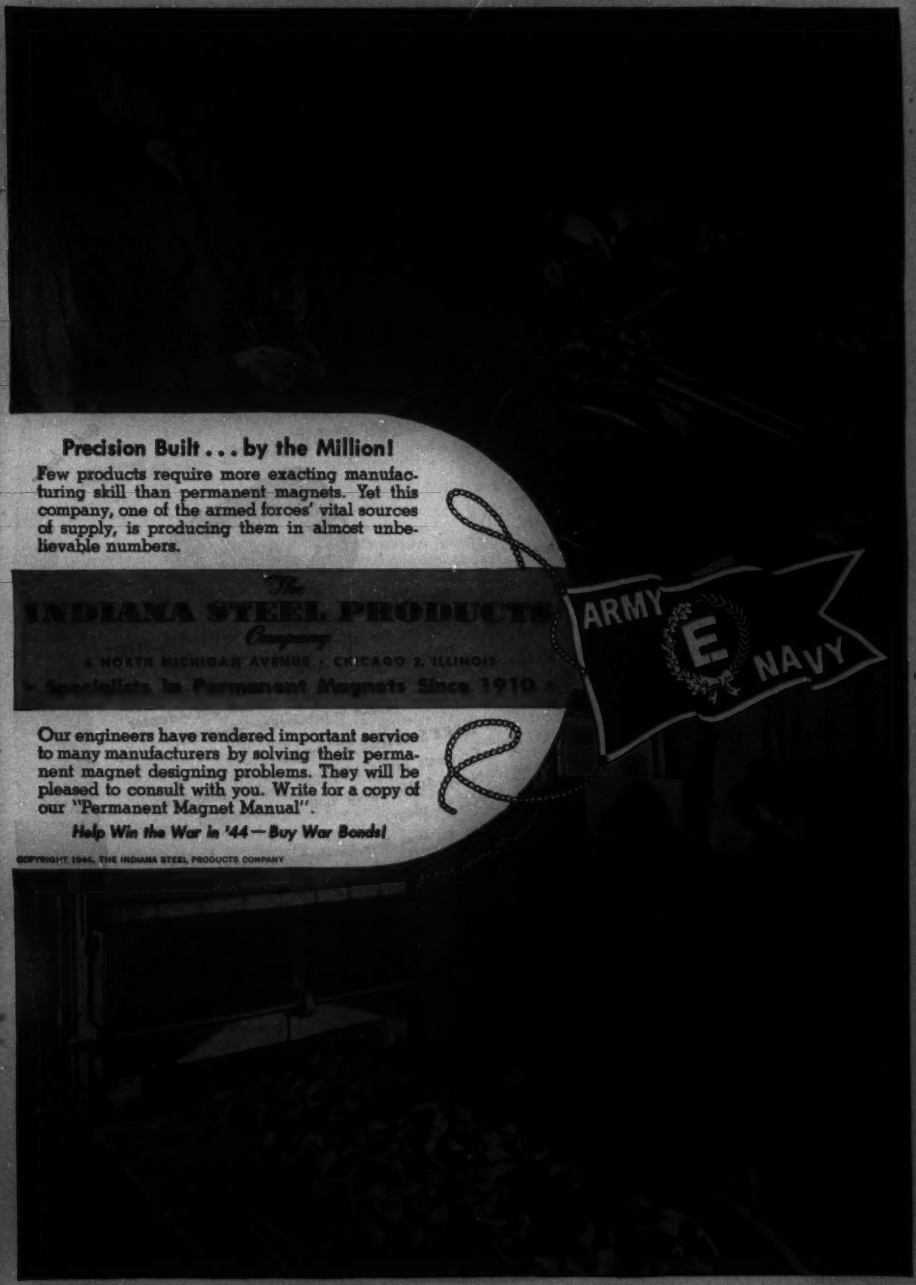
PERMANENT MAGNETS MAY DO IT BETTER



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ARMY E NAVY

Our engineers have rendered important service to many manufacturers by solving their permanent magnet designing problems. They will be pleased to consult with you. Write for a copy of our "Permanent Magnet Manual".

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A Good Firm to Connect With For Your Postwar Needs in:

CONNECTORS AND RELATED UNITS

Connector Division of IRC produces a comprehensive line of coaxial cable connectors, multiple contact connectors and cable plugs.

If your postwar products call for these or other small parts of a related nature, we suggest you avail yourself of our specialized knowledge, experience and volume manufacturing facilities. Inquiries are invited.

NEW COAXIAL ADAPTER

Adapts British to American Coaxial Connectors

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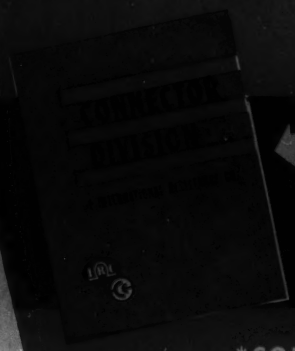
HERE'S WHAT IT DOES

Connects British 10H/528 coaxial plug to the Navy 49195 plug and to the Signal Corps PL-259 plug.

Meets Navy Specifications RE49F243



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SEPTEMBER

1944

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IT'S THE QUALITY OF PERFORMANCE THAT COUNTS

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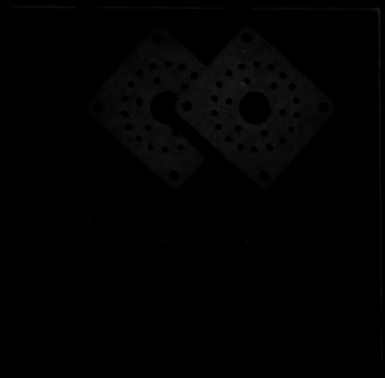

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40th YEAR OF CERAMIC LEADERSHIP

ELECTRICAL ENGINEERING
VOLUME 63, NUMBER 9 SEPTEMBER 1944

The First 60 Years of the AIEE

NEVIN E. FUNK
FELLOW AIEE

The modest beginnings of the Institute in 1884 at the time of the international electrical exhibition in Philadelphia, Pa., and its growth and expansion into a professional organization of international standing are described in this article. AIEE's contributions to the war effort also are recounted.

THE INSTITUTE'S 60th birthday was the 13th of May 1944. The first 50 years of our history have been presented in the golden-anniversary number of *Electrical Engineering*;[1] in it most of the then living past presidents individually covered some specific part of the many activities of the Institute in a comprehensive way. I will not attempt to duplicate that information.

A few days after the Institute's birthday had passed, the 100th anniversary of sending the first electric-telegraph message was celebrated. The telegraph industry was 40 years old and a well-established going business when the Institute came into being. It is not at all surprising that the list of names of the 25 men issuing the call for the organization meeting contained 21 telegraph men and only four representing other industries.

The urge to establish a national electrical society in the United States was precipitated by the arrangements which had been made by the Franklin Institute to hold an international electrical exhibition in the city of Philadelphia during September and October 1884; the electrical men in the United States thought it would be a lasting disgrace to Americans if there were no official national electrical organization to welcome the foreign dignitaries who came to visit this exposition.

The Institute was formally organized on May 13, 1884, and Norvin Green, then president of the Western Union Telegraph Company, was elected its first president. Norvin Green was born in New Albany, Ind., in 1818, but spent his early life and received his education in Kentucky, beginning his business career as a physician. Doctor Green, however, became interested in politics and was elected for a number of years as member of the Kentucky legislature. In 1853 he was appointed Commissioner of the United States in charge of the construction of national buildings in Louisville. It was while he was engaged in these duties that he became interested in the United Morse and People's Telegraph Lines between Louisville and New Orleans.

There were many small independent telegraph companies in those days, and Doctor Green believed that they should be consolidated into companies which could give universal telegraph service. He was the first president of the Southwestern Telegraph Company, which combined the telegraph lines between New Orleans and Louisville. In 1886, when the America, the United States, and the Western Union companies were consolidated into the Western Union Telegraph Company, Doctor Green was chosen vice-president and held this office until 1878 with the exception of three years, during which he was president of the Louisville, Cincinnati, and Lexington Railroad Company. He was elected president of the Western Union Telegraph Company in 1878, and held that office until his death in 1893 at the age of 75. Doctor Green was an ardent worker for the establishment of the Institute, and his foresight and optimism were very helpful in the early days of its existence. He was one of the four men to serve two successive years as president of the Institute.

Although the Institute was founded primarily by men of the telegraph industry, almost immediately its work was dominated by the men of other rapidly growing branches of electrical activity. For the first 15 years of its life, of the papers and discussions presented, only three per cent pertained to the telegraph industry; 80 per cent referred to a-c practice and theory, traction, motors, dynamos, prime movers, electric transmission, lighting, fundamental units and Standards; and a scattering was devoted to specialties like the production of aluminum, welding, and therapeutics. The rapid growth of other interests than that of telegraphy also is indicated by the fact that of the first ten presidents only two were connected with the telegraph industry, although that industry had been in operation for 40 years.

When Norvin Green was elected to the presidency for the first time he was 64 years old, and was one of only three presidents during the next 30 years who were over 47 years of age. The reason for this, of course, was that the expanding young industry was being operated by young men. The average age of the presidents when elected to office during the first two decades of the Institute's history was 42 years, as compared to 56 years for the last two decades, and is again indicative of the fact that the beginning of the present electrical industry was almost wholly in the hands of young men.

From its very earliest beginning, the Institute has presented a forum for the expression of individual opinions and the discussion of electrotechnical subjects. It was this opportunity for exchanging ideas and the work done by the various committees which aided in the rapid progress that took place in the early beginnings of the industry and which has so greatly affected almost every activity in our lines.

One of the earliest committees, units and Standards, later changed to the present Standards committee, shows that the founders of the Institute appreciated the necessity of establishing Standards early in the life of the industry. One can well understand the chaos which would have resulted if there had been no guiding hand and each manufacturing establishment or user had followed his own inclinations. Standards were established for the performance of various types of apparatus having to do with efficiency, temperature rises, types of insulation, rating, regulation, classification of voltages and frequencies, overload capacities.

The co-operative manner of establishing these Standards was such that progress was not impeded in the very rapidly advancing technique of the electrical industry, and it is hard to conceive how this progress could have been accomplished other than through the office of the Institute committees.

The work of the Institute was not confined alone to physical Standards, but was carried further into the standardization of abbreviations and the development of standard definitions of electrical terms

Essential substance of an address delivered at the 60th anniversary commemoration held during the AIEE North Eastern District technical meeting, Boston, Mass., April 19–20, 1944.

Nevin E. Funk, president of the Institute at the time this address was made, is vice-president in charge of engineering of the Philadelphia Electric Company, Philadelphia, Pa.

which facilitated the correct communication of ideas. Neither were the Institute's activities confined to committee work wholly within the Institute organization; very shortly after the turn of the century representatives were appointed to joint committees with other technical organizations both in America and abroad, thus giving the Institute an international standing.

The opportunity to discuss openly scientific problems has promoted the intellectual development of all the members of the Institute and broadened their opportunities for increased knowledge at a much greater pace than otherwise would have been possible. Books written by individuals usually contain only the author's ideas or his interpretation of the thoughts of others, and the length of time required for preparation always makes publication materially behind the performance of industry. The publications of the Institute, however, present information following closely on the heels of performance and are able to offer many different approaches to problems pressing for solution, because of the opportunity furnished for many individuals to express themselves. In the works of the Institute we are always able to lay our hands on up-to-date sharpened mental tools with which to approach our tasks.

During the Institute's lifetime, of course, many committees have been formed and later passed out of existence when the need for them disappeared. However, the number of committees has grown from a mere handful in the 1880's to 43 in 1934 and 55 today. Our representation in joint efforts with other organizations, which did not begin until after 1900, grew with extreme rapidity until we had representatives on some 33 organizations in 1934, which has been expanded to 37 today.

The growth in membership of the Institute led in 1893 to the consideration of the desirability of holding meetings in some of the other large cities, besides New York, and a plan was adopted in November of that year providing for holding local meetings in any city upon the petition of 20 members. Subsequently, monthly meetings were held in Chicago, usually on the same evenings as the meetings in New York. So that in 1893 we find in effect that the Institute had one local Section, although it was not known as such.

In 1902, the board of directors approved the organization of local groups known as Sections and Branches, and the number of Sections grew with great rapidity. By 1934 we had 61 local Sections and 113 Student Branches. Today we have increased our local Sections to 73 and our Student Branches to 125. In membership we grew from an initial 71 in 1884 to over 18,000 by 1927. As a result of the depression this number had dropped down to 15,000 in 1934, but has increased so that today it is over 22,000. This expansion in membership which continued at an ever-increasing rate without any reversal in trend from the date of organization until 1927 is in itself a positive indication of the marked influence which the Institute has had in both the industrial and educational fields.

AIEE CONTRIBUTIONS TO WAR EFFORT

War activities are foremost in our minds today, and the contributions which the Institute has made are not so generally known as they might be. We did not wait until after Pearl Harbor to begin these activities. On June 27, 1940, the board of directors adopted a resolution to offer the services of the Institute to the President of the United States in connection with any problems of national defense in which they might be of aid. In January of the next year the committee on air transportation notified the Army–Navy Aeronautical Board that it was in a position to be of aid in connection with the development and co-ordination of aeronautical electric equipment. At the same time the Institute committee on national defense was appointed with Comfort A. Adams as chairman, and John C. Parker was designated as the Institute's representative on the National Technological Civil Protection Committee appointed by the Secretary of War. The Institute also organized a civil protection committee in 1941, with Doctor Parker as chairman, and appointed five representatives on the Engineers Defense Board, which consisted of representatives from six different engineering societies. This board completed certain studies on critical materials and was dissolved in 1942.

In the same year, the committee on national defense and the civil protection committee were combined to form the committee on co-operation with war agencies. At this period the Armed Forces were searching for technical specialists of many types who would be able to meet the requirements for commissions in the services, and this new committee, with the assistance of the Institute Sections, submitted more than 600 names from which many highly qualified officers were secured. This committee also appointed three subcommittees for specific activities; one engaged in a comprehensive collection and distribution of information on the conservation of critical materials; another assisted the Signal Corps in the establishment of a technical reference library; and the third acted in an advisory capacity on the allocation of technical man power.

The Institute also appointed a special committee to co-operate with representatives of the conservation division of the War Production Board on the substitution of silver for copper and aluminum in electrical installations. This committee was able to report very specific recommendations regarding some substitutions which were feasible.

The Standards committee carefully considered the many technical problems involved in the preparation and use of war emergency electrical Standards. It concluded that in a great majority of cases wartime requirements could be met effectively by the preparation of wartime guides and interim reports covering the application of various types of standard electric apparatus under emergency conditions.

Therefore, the Standards committee, in collaboration with the technical program committee and the committee on co-operation with war agencies, recommended that the Institute's technical committees prepare guides and reports covering the economical application and operation of electric apparatus under these conditions, and that wherever necessary emergency substitutions or modifications of present Standards be developed.

Many of these guides have been completed. They are educational in character and are in no way mandatory. They are intended to make essential information immediately available to war industries, thus furthering conservation of critical materials and labor, and they cover many types of equipment, including shunt capacitors, power cables, circuit breakers and switchgear, generating equipment and systems, system-grounding impedance, industrial power-distribution systems, electric motors and controllers, automatic-reclosing equipment on stub feeders, power transformers and regulators, distribution transformers, current-limiting reactors, lightning arresters, conductors for supervisory control and telemetering, and out-of-step relay protection.

There was an immediate need for a modification of one existing Standard, 45, "Recommended Practice for Electrical Installations on Shipboard," and it was produced by the committee on marine transportation under the title, "Modification of and Supplement to AIEE Standard 45." It is to apply during the emergency only.

Since the fundamental objective of the Institute is the advancement of the theory and practice of electrical engineering, the technical papers and the electrical Standards produced in peacetime are even more useful in wartime when new ideas must be used to the maximum extent. To increase its contributions in these fields the Institute has put major emphasis upon activities closely related to the war effort, and technical papers, publications, and Section meetings are devoted to subjects closely related to this theme insofar as practicable. All committees are expected to conduct their work in accord with the spirit of this policy.

In addition to the requirement that insofar as practicable all technical papers accepted shall be closely related to the war effort, some 25 sessions and conferences of national and District meetings have been devoted to such topics as substitution of materials, defense lighting, electric equipment for military aircraft, emergency loading of transmission systems, distribution

systems in wartime, problems of engineering education, and technical personnel in wartime.

Also, a great many of the Institute Sections have held meetings connected with various phases of the war effort, including a considerable number of production clinics, held in co-operation with the War Production Board and other engineering societies, which were intended to expedite production of war materials, and also meetings on conservation of critical materials.

The Institute is represented by its national treasurer, W. I. Slichter, on the Joint Committee on Inter-American Engineering Co-operation, which was organized in 1941 to study methods of increasing engineering co-operation among the countries of North and South America, and in particular to develop an interchange of technical publications and engineering standards. Professor Slichter is also chairman of the Institute's own committee on Inter-American engineering co-operation.

In August 1943 the board of directors authorized the appointment of a special committee to consider methods through which the Institute might be helpful to Chinese engineers. Vice-President C. R. Jones was appointed chairman. With the co-operation of the American section of the Chinese Institute of Engineers and the Office of War Information, the committee has arranged for the transmittal on microfilm to technical centers in China of about 1,000 pages selected from the 1943 *Transactions*, about 900 pages of electrical Standards, and about 100 pages from *Electrical World* for 1943; and for the transmittal in book form of copies of electrical engineers' handbooks and a few electrical textbooks.

The Institute prepared a series of six radio programs on the work of electrical engineers in defense problems, which were broadcast early in 1941. Several engineering societies co-operated in a series of 11 broadcasts beginning in July 1942, which supplied much information on the place of engineers in war work.

Over 2,000 Institute members are serving in our Armed Forces. Two members of the Institute board of directors are in the Navy: F. R. Maxwell, Jr., as a commander at United States Naval Air Station, Pensacola, Fla., and W. B. Morton as a lieutenant commander in the Philadelphia Navy Yard. Three members of the headquarters staff were called into the Armed Forces: G. Ross Henninger, editor, serving as a lieutenant colonel in the Air Service Command, Patterson Field, Ohio; W. R. MacDonald, Jr., assistant editor, first lieutenant in the Signal Corps Reserve, called into active service in January 1941, promoted to captain, later to major, and now released from active service; and John J. Anderson, Jr., of the Standards department, serving as an ensign in the Navy. Colonel Henninger had, for several months before entering the Army, assisted the Navy Department on a part-time basis in the organization of an editorial and publication review section.

Other members of the headquarters staff have assisted as fully as possible in connection with a great many requests of wide variety from the Armed Forces and divisions of Government. In particular, service has been rendered in the development of the electrical-engineering check list of the National Roster of Scientific and Specialized Personnel in the search for men qualified for many types of technical work, a compilation of census of engineering construction firms, the extension of subcontracting plans, and a study of supply of and demand for engineers and greater use of smaller war plants. Beginning in June 1943, the Institute has published a four-page quarterly AIEE *Bulletin* for members in the armed services and the merchant marine.

A great deal of information regarding war activities of the Institute, divisions of the Government, and other organizations has been published in *Electrical Engineering*, and special attention has been given to any types of information which would assist in securing electrical engineers qualified to meet the many needs for technical men in the Armed Forces and in other organizations.

REFERENCE

1. *Electrical Engineering* (50th-anniversary number), volume 53, May 1934.

The Future of Aeronautics

R. DIXON SPEAS

The general future of air transportation and the nature of problems that are of immediate and future concern in the design and operation of civil aircraft are foretold in this article by an airline executive.

MANY contradictory pictures of air transportation in the future have been painted which vary from rosy optimism to the darker shades of pessimism. Just what may be expected realistically during the first ten years of peace?

Air transportation may be divided for discussion into three categories: types of aircraft, routes to be flown, and magnitude of the industry. With reference to the first, civil transports of the next three or four years now are flying in military service. A military cargo plane originally designed for service on the airlines has been performing spectacular transoceanic flights in military service for months. Currently the airlines are operating the Douglas *DC*-4 in the military service as the *C*-54 and obtaining thousands of hours of transport operating experience. When the time comes to return this long-range transport to the civil task for which it was originally designed, the engineering information thus gained will give air passengers the ultimate in speedy long-distance air transportation for the immediate postwar era.

With the long-range airplanes such as the Constellation and *DC*-4, such schedules may be expected as Boston to Los Angeles between breakfast and dinner of the same day with 40 to 50 passengers carried in club-car luxury as soon as aircraft can be spared from their military transoceanic tasks in this war. A conversion period of approximately six months probably will be required for readying this equipment to its civil tasks.

So much for the more spectacular view of air transportation to come. With regard to the mechanical details of these aircraft, all are equipped with hydraulically controlled landing-gear-retracting mechanism, brakes, and landing flaps, which are the main functions requiring major auxiliary power transmission on present-day airplanes. For the next five to ten years there will be gradual improvement in the basic design features of transport airplanes, including increases in size, speed, and comfort from 50 to 100 passengers, 250 to 325 miles per hour cruising speed, and general improvement in luxuries provided. As

Essential substance of an address presented at the Institute's 60th anniversary observance during the AIEE North Eastern District technical meeting, Boston, Mass., April 19–20, 1944.

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The author acknowledges the assistance of William Petrasek of American Airlines, Inc., in the preparation of material for this article.

for electrical versus hydraulic features of these aircraft, the answers will depend in a large measure upon the electrical and the hydraulic engineers.

The second phase of air transportation in the future concerns routes to be flown. At the present time airways all over the world are being operated by the domestic airlines of the United States as well as the international carriers. Domestic route mileages flown, however, have decreased somewhat as compared to prewar standards. As for the future, transport aircraft may be expected to operate under all atmospheric conditions which exist in this world from the 100-degree temperatures of the equator to the subzero temperatures of the arctic areas. The route advantages of flying the arctic areas will undoubtedly increase in time to come, with increased flight range of new equipment and the requirements for improved services between the continents becoming more pronounced. For the immediate future commercial air routes probably will not be directly over the poles. Many more airways may be expected over the arctic than over the antarctic area, and design criteria for operating equipment are therefore based on atmospheric conditions of the arctic. Operating altitudes of airliners have gradually increased to present-day limits of 15,000 to 20,000 feet. Further increases to 30,000 feet may be expected during the next ten years, so that operating accessories must be designed with corresponding pressures in mind.

Magnitude of air transportation will depend upon the utility which American industry and the public are able to find for air transportation as well as the degree to which air-transportation systems are able to provide desirable services. In general, a five-fold increase in the air transportation industry may be expected during the next ten years, with a fleet of over 1,000 transports in active commercial service by 1950.

Probably the most important electrical problem in aircraft today, power transmission, which refers to such operations as retraction of landing gear, manipulation of flap controls, application of brakes, and other such items, is of a competitive nature, having been met with hydraulic and mechanical solutions as well as electrical designs. The choice between electric, hydraulic, or mechanical transmission fundamentally must be decided upon factors of reliability, ease of maintenance, and weight. The major present-day and immediate-future transports utilize hydraulic and mechanical systems for practically all power transmission. The ingenuity of electrical engineers is now challenged to devise and develop electrical equipment of corresponding or improved reliability, ease of maintenance, and weight. Applications in this respect have been applied to aircraft in the past, and further applications of such electrical systems in military aircraft now are being witnessed. The airlines are studying closely the experience gained in these military aircraft. The fact that ground power transmission by electrical means has been so outstandingly satisfactory for industrial application with regard to flexibility, reliability, and economy, lends considerable support to the thought that corresponding developments can be made in applications to the aircraft field.

A second important problem which in some measure depends upon solution of the power-transmission problem concerns the actual electric system to be provided. Basically, the problem is whether medium-voltage direct current or medium-voltage alternating current should be used for the newer and larger transports of the future. Practical application of an a-c system on aircraft awaits the development of a suitable constant-speed device for holding generator speed constant under conditions of varying engine speed, that is, the airplane engine operates under normal cruising conditions at varying speeds. A direct-drive device, therefore, is not satisfactory for a-c generation of a constant frequency, and a completely satisfactory constant-speed drive of reasonable weight has not yet been developed. Here again in the choice of an electric system, the basic determining factors of reliability, ease of maintenance, and weight are of paramount importance. Current air-transport planes utilize 12- and 24-volt d-c systems for all primary electric power.

A definite trend in aircraft-battery design is at present providing higher and higher voltages in the interests of saving copper. In general, it can also be said that the importance of storage batteries is decreasing.

A third problem is one of cockpit lighting. One of the airlines' most pressing problems of today from the standpoint of cockpit engineering is lighting. The conflicting demands of adequate lighting of instruments and outside visibility requirements are all associated with problems of glare, reflections, and refractions as well as the illumination problems. Any lighting engineer searching for fertile fields where research and development are desperately needed will do well to study cockpit-lighting problems. For, despite many outstanding developments, the airlines are still seeking more satisfactory solutions.

The matter of power generators also merits careful consideration on every new airliner. Until recently practically all power generation was by engine-driven generators with substantial storage-battery capacity. The trend has been toward increased generator capacities with less dependence on storage batteries. In some of the larger installations auxiliary gasoline-powered generators units have been proposed, and thoughts have turned to the utilization of engine-exhaust waste heat. Further research and development are required to determine the best over-all power-generator arrangement to provide equipment for that purpose.

Service equipment for airliners in the form of food warmers, liquid heaters, and hot plates for cooking is becoming of increasing importance to the electrical engineer. At first glance the respective problems appear to be quite simple in view of the multitudinous previous applications of corresponding equipment. Aircraft requirements of low weight and ease of maintenance, however, have so complicated the problems that today almost all food preservation is done by means of vacuum-bottle equipment. An electrical engineer with a desire to develop applications of heating units to airline operation will find his efforts welcomed by airlines.

Until the present time utility has been the main governing factor in all electrical designs for passenger-compartment lighting. The decorative feature now has increased in importance so that further research and development in this regard are required. The decorative values in lighting can be much more widely utilized in improving the interior design features of transport aircraft.

The tremendous developments in the electrical field during this war will do much toward meeting the corresponding problems of civil air transport. All such developments are being closely followed. Other problems, however, demand that the airlines secure the most ingenious application of electrical-engineering principles to air transportation.

Photo courtesy Transcontinental and Western Airlines

The Lockheed Constellation

Arthur H. Kehoe—1943 Lamme Medalist

The Lamme Medal

S. B. WILLIAMS
MEMBER AIEE

The 16th presentation of the Lamme Medal was made at the recent AIEE summer technical meeting in St. Louis, Mo. The award was made "For pioneer work in the development of a-c networks and associated apparatus for power distribution."

MEDALS are awards for valor. Just as many of our young men who are fighting the enemy are decorated for brave deeds, so do we today honor a man for his courage—not for physical intrepidity but for mental daring.

Because we honor our scientific and engineering heroes only after the battle has been won and we are able to weigh the merits of the achievement dispassionately, we lack the emotion that accompanies a decoration on the field of battle.

That is unfortunate because a medal is awarded not only as a recognition for courage but also as a means for inspiring others to exert themselves beyond the line of duty. The awarding of a medal should not be regarded as the closing of the record on some splendid achievement so much as the opening of the gates of new imagination.

This profession of electrical engineering needs inspiration of this kind so badly. The opportunities are greater today than ever before because the problems are more numerous. Yet the romance that was ours when Mr. Lamme lived has been dulled. We must restore it if we are to attract to the profession the young men whose desire is to create.

Mr. Lamme must have had something of this nature in mind when in an article for the *Ohio State Engineer* on "The Electrical Engineer of Today" he opened with these words: "The engineer views hopefully the hitherto unattainable." And the AIEE when it accepted the trust under Mr. Lamme's will must have had a like thought when it put those words of Mr. Lamme on the obverse of the medal.

The Lamme Medal is awarded annually by the AIEE for "meritorious achievement in the development of electrical apparatus or machinery" and was made possible by a bequest in the will of the late Benjamin Garver Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company, who died 20 years ago. This medal is made of gold, the obverse of which has been mentioned. The reverse represents Niagara, for the harnessing of which Mr. Lamme designed the great electric generators.

Like all medals, however, the value lies not in its intrinsic value but rather in the roll of those who have received it. For that reason I would like to read the names of those who have received the medal, and add the name of the latest recipient. It is a list that adds luster to the award.

1928 *Allan B. Field*—"For the mathematical and experimental investigation of eddy-current losses in large slot-wound conductors in electric machinery."

1929 *Rudolf E. Hellmund*—"For his contributions to the design and development of rotating electric machinery."

1930 *William J. Foster*—"For his contributions to the design of rotating a-c machinery."

1931 *Giuseppe Faccioli*—"For his contributions to the development and standardization of high-voltage oil-filled bushings, capacitors, lightning arresters, and numerous features in high-voltage transformers and power transmission."

1932 *Edward Weston*—"For his achievements in the development of electrical apparatus, especially in connection with precision measuring instruments."

1933 *L. B. Stillwell*—"For his distinguished career in connection with the design, installation, and operation of electric machinery and equipment."

1934 *Henry E. Warren*—"For his outstanding contributions to the development of electric clocks and means for controlling central-station frequencies."

1935 *Vannevar Bush*—"For his development of methods and devices for application of mathematical analysis to problems of electrical engineering."

1936 *Frank Conrad*—"For his pioneering and basic developments in the fields of electric metering and protective systems."

1937 *Robert E. Doherty*—"For his extension of the theory of a-c machinery, his skill in introducing that theory into practice, and his encouragement of young men to aspire to excellence in this field."

1938 *Marion A. Savage*—"For able and original work in the development and improvement of mechanical construction and the efficiency of large high-speed turbine alternators."

1939 *Norman W. Storer*—"For pioneering development and application of equipment for electric traction."

1940 *Comfort A. Adams*—"For his contributions to the theory and design of a-c machinery and his work in the field of electric welding."

Arthur H. Kehoe receiving the Lamme Medal from President Nevin E. Funk in the presence of H. R. Searing, who introduced the medalist

S. B. Williams is editor of *Electrical World*, New York, N. Y., and chairman of the AIEE Lamme Medal committee.

1941 *Forrest E. Ricketts*—"For his contribution to the high reliability of power-supply systems, especially in the design of apparatus for selective relaying and circuit reclosure."

1942 *Joseph Slepian*—"For his contributions to the development of circuit-interrupting and current-rectifying apparatus."

1943 *Arthur H. Kehoe*—"For pioneer work in the development of a-c networks and associated apparatus for power distribution."

Career of the Medalist

H. R. SEARING
FELLOW AIEE

IN sorting and clarifying my impressions of Arthur Kehoe, I labor under a certain difficulty—I have been so close to him for over 30 years that I now have to change my focus in order to bring to you a proper picture of the engineer and the man.

From his birth in Vermont in 1889, through the years of his basic education there, culminating in his graduation with the degree of bachelor of science in electric engineering from the University of Vermont in 1911, which university, incidentally, last month conferred upon him the honorary degree of doctor of engineering, he breathed the well-known atmosphere of individualism of that rugged state. It is easy to understand how that environment and that early Vermont training would develop his outstanding trait, namely, a tenacity and persistence in seeking out and developing methods of improving the way things are done. Equipped with a keen engineering mind, without predispositions, he has been able to evaluate shrewdly the results of research and new developments, to visualize methods of practical application, even to design tools, apparatus, and equipment where necessary to bring about the final accomplishment. That is the basis of the success which is being recognized here today.

Shortly after graduating, he was employed in The United Electric Light and Power Company in New York, N. Y., as an engineering assistant. This was a relatively small company which distributed a-c service underground in the Borough of Manhattan. With characteristic boldness, energy, and perseverance he delved into all phases of the company's activities; small problems and large ones had his attention. As a result of his detailed study of performance, trends in metering were changed and radical changes were made in the design of substations and substation equipment, particularly the control apparatus.

At that time, the greatest supply of electricity in Manhattan was direct current distributed by the New York Edison Company. This was a supply of a great degree of dependability—indeed, the only supply adequate to the exacting standards of that densely populated city with its tall buildings. He learned that the New York Edison Company had a national reputation because of its exceptional record of service continuity. Fundamentally, this service was direct current from a network backed by storage batteries. "Why not a comparable a-c service?" asked Kehoe. Obviously, the product his own company had to sell—alternating current in its then stage of development—was not able to compete with New York Edison Company service on equal terms for the peculiar electrical requirements of the metropolitan market.

The question of a-c service from a network was not new, but analysis of the scope of the problem brought realization of the obstacles that had to be overcome. These obstacles were imposing: the system would need to be distinctly more economical than the d-c network system; the apparatus would need to perform as well as the long-tried and long-developed d-c apparatus; no complicated operational procedures to bolster the failures of design or construction could be tolerated. Moreover, the fundamental factor, how to apply alternating current to a network, was not known, and the specific apparatus that would be required had not been designed. To one who was not convinced that the conception could be worked out, the problem would have appeared too difficult to solve. But Kehoe not only was convinced it could be worked out but that it would have to be worked out to meet the electrical future of New York. He sensed the mounting costs in the extension of the d-c network system and also that the limitation of duct space and conductor size or cable temperature practically prohibited greater loads on the system. These realizations whetted his determination to conquer the problem and served to counteract the discouragements which came along, as they always do.

These are some of the utilization, engineering and design factors that had to be determined and resolved:

1. With one set of service mains for both light and power, how much variation of incandescent-lamp illumination, due to voltage changes, would be permissible?

2. The performance of high-voltage and low-voltage cables under fault conditions had to be determined, in order to design the proper cable and develop means of protecting it, always with a view to maximum reliability at minimum cost.

3. Changes in transformer design had to be made to assure the safe operation of a network fed in multiple from the secondaries of transformers, a number of transformers being connected to any one of several radial high-voltage feeders.

4. It was necessary to design and assemble a combination of fuses, circuit breakers, and relays that would respond automatically and in proper sequence to fault and operating conditions.

The first installation of the network system was placed in service in April 1922. It consisted of 29 switches, supplied from four high-voltage feeders. The then available transformers, relays, cables, circuit breakers, fuses, and other accessories were used. These, however, had been greatly modified in design to meet the demands of the new system. While many of the elements existed, it was Kehoe who engineered the modifications and combinations of the elements, and introduced other elements. In short, much adaptation of existing material and equipment was done at little expenditure of money. Success depended almost wholly on the foresight and imagination of the planner. By his broad conception and practical mind, the automatic a-c network was brought into being. The story of the initial installation and the early operating results was given to the profession by Kehoe at a meeting of this Institute at Chicago in June 1924. Moreover, Kehoe in this paper predicted that a-c network distribution would have profound effects upon generating-station and system design. You who are familiar with such matters know how rapidly this prediction has been fulfilled. Today, the low-voltage network system, as started in 1922, is used in at least 165 communities. The peak load serviced by low-voltage networks in 1943 was approximately 2,125,000 kw. The total installed transformer capacity was over 4,600,000 kva.

Reference could be made to the patents issued to Mr. Kehoe, to the technical papers he has contributed, to his active participation in civic affairs, and to his help in the establishment of sound educational work in engineering. I might refer, also, to some things in which he has failed—notably in his effort to identify golf balls with his initials because he has not succeeded in placing the initials on the ball in such a manner as not to unbalance the ball.

All of this would not suffice to describe the outstanding worth of the man. In all his work he has been modest, has shunned the spotlight. His method has been to foster the development of others by providing them with the opportunity to demonstrate their abilities. He would pose the problem, he would suggest possible solutions, he would give the man his head, he would be a constant source of encouragement and inspiration to the one striving honestly for a result.

Many young engineers, and some others now grown both in years and wisdom, would join me, I am certain, in being thankful that we had the benefit of this man's guidance.

H. R. Searing is executive vice-president, Consolidated Edison Company of New York, Inc., New York, N. Y.

We believe that Benjamin E. Lamme, the donor of the medal, would look with favor on the committee who selected Arthur H. Kehoe to be the recipient of the medal, and we who have known him for years are elated to have his name added to the list of those illustrious men on whom the medal previously has been bestowed.

Story of the A-C Network

ARTHUR H. KEHOE
FELLOW AIEE

IT is doubtful if a reasonably complete story of the contributions which a select group of men made at considerable risk during the development of successful multiple-feed a-c network distribution has ever been compiled. I feel I owe it to them to start one, since their work, which has had scant recognition, caused mine to be noted.

My tale, like many pertaining to the practice of electrical engineering up to this time, has its root in the character of, and the struggles with, insulation that is to be found in practice. At some future date, perhaps in this next decade, engineers may wonder why any of the contributions which I will discuss were ever considered important. When they can take such a view, insulation and also the practice of electrical engineering will have changed for the better.

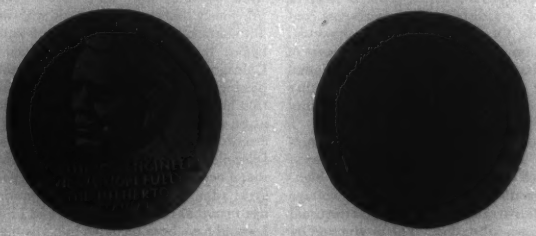
Early in this century, on Manhattan Island south of 135th Street, the great New York Edison Company d-c distribution system had a small competitor using underground a-c distribution. The Edison Company was the premier system for almost any conplimentary characterization one might wish to make and its service was so excellent that many in New York were unaware that there was any other service. While a giant–pigmy situation existed, nevertheless the little United Electric Light and Power Company system was by far the largest underground a-c distribution system in the United States since at that time most a-c systems consisted of a minimum of underground cable and a maximum of overhead lines. Although we were not the only system having insulation failures, we had a concentration that was not experienced elsewhere.

Our system used radial underground circuits of the three-kilovolt class. Distribution transformers were air cooled and located in vaults on consumers' premises, and had their secondaries connected to low-voltage cables in the streets. Each circuit from a substation had a few principal branches, which in turn supplied a number of the transformers that were joined in a network by the street mains in the area fed by that branch. These distribution circuits were highly developed in order to locate faults promptly and eliminate their effects.

Failures provided a hectic existence and it did not take genius of a high order to suggest that interruptions would be minimized if all the small radial networks on a number of circuits were interconnected and each transformer secondary was provided with a reverse-trip switch to open when a fault occurred on the circuit feeding its transformer. This arrangement was proposed in 1912. At the time suitable circuit breakers were unknown, except possibly those in the form of motor-starting contactors, and existing reverse-energy relays were too expensive to put at every transformer. Furthermore, there were serious reservations as to supervision of automatic equipment on so many consumers premises, both due to costs and to limited accessibility. The alternative of using switches that were fully automatic was intriguing but required development of a new and radical type of equipment for that day. The answer, of course, was to continue the accepted practice: use automatic double-throw switches on the more-important installations, while continuing distribution-transformer fuse-blowing network protection of the McCoy and Sprong type, as well as making better installations and better fault-hunting conditions.

In 1913, G. E. Palmer, a manufacturer of Boston, had produced a circuit breaker for remote electrical operation which encouraged a review of the 1912 proposal. When the requirements were explained, he promptly produced a satisfactory switch. For a time following the delivery of this Palmer circuit breaker, he accepted our conclusion that we in New York were the relay experts. Soon he surmised in his keen way how little more we knew than he did of relaying and then began spending time and money for the entire development. By 1916, H. R. Searing and W. R. Bullard, along with some of our laboratory staff, were working on network equipment and also on types of combined service for both lighting and polyphase motors. At this date it was generally agreed by those interested that there would be required for a successful installation a full-automatic network switch which would open on a reversal of energy as small as the magnetization value of its transformer and would close only when circuit conditions were such that the transformer would supply load when connected to the secondary network. The phasing circuit across the open switch, having in series a variable resistance in the form of tungsten lamps, was settled upon and has had extensive use ever since. However, the reverse-energy feature, which numerous calculations indicated to be possible as designed, did not emerge from the laboratory as being within operating limits although many variations were tried. All types of current transformers or shunts with different relays were reported as failures either at transformer-magnetization values or at full load including the momentary short-circuit values of 10 to 20 times transformer full load. The principle of a saturating circuit for protective relays, previously developed by F. E. Ricketts of Baltimore, the Lamme Medalist of 1941, was applied in these various attempts without satisfactory results. No one up to that time was known to have produced a metering or relay circuit with such an extended range of operating values as was needed for the network switch.

Meanwhile, World War I threatened, and finally broke on us. The industry experienced rapidly increasing demands for electric service, the desirability for a uniform service throughout the United States, a shortage of materials, and a scarcity of money to make the necessary expansion which was combined with rising prices and reduced return under our fixed rates. Such happenings brought the first rumblings of change in d-c systems throughout the country. Before the end of the war in 1918, Lamme had presented a paper before the Institute on the "battle of the frequencies." It was an excellent sample of postwar planning for 60 cycles. The period immediately following the war brought to the fore subjects such as elimination of standby storage batteries in d-c substations, restriction of d-c



The Lamme Medal, established in 1926

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growth, and cutting over d-c loads to alternating currents. Such questions resulted in engineering discussions on d-c substations to be started from a-c sources, a-c starting of rotary converters versus the use of motor generators, and the frequency of the supply for future d-c loads.

The discussion arising concerning d-c systems of the time also brought forth many suggestions for changes in a-c systems. As a result, pioneering occurred in many places with end results which, while not uniform, provided the structure with which the electrical industry has been able to meet all the vast and varied demands of this present world struggle. Distribution took the following course: Philadelphia, first with W. C. Eglin and later P. H. Chase; Brooklyn with J. C. Parker and H. R. Woodrow; New Orleans and other Electric Bond and Share Company companies with A. E. Silver; and a number of midwestern and Pacific Coast cities, particularly Seattle, were all strong proponents for radical change from the established d-c system and so their spokesmen were leaders in suggesting improvements in a-c service. Of course the forum of discussion was a restricted one as the use of direct current was generally limited to the densely loaded city areas and d-c service was excellent for those days except as to the matter of costs.

Meanwhile the United Company in New York was developing a strong group of men who later contributed so much to developments. Searing, returning with valuable war experience, produced the closest approach to a successful network relay to operate a Palmer-type switch. This was a Kelvin-balance-type relay to obtain an extended range with an "over the hump" type of operation. Bullard, followed shortly by C. W. Franklin, G. R. Milne, J. E. B. Stuart, and E. R. Thomas, took up the many problems in detail and resolved them one by one, producing solutions that have stood the test of time. At this time Seattle, facing a problem of developing *de novo* a city district, wanted to get proper results with a system which would show reduced costs compared to extending their d-c system. The experimentation proceeding in New York had come to their notice, and in 1920 M. T. Crawford rechecked but found the apparatus development not yet satisfactory for full-automatic switching. Seattle then in 1921 made the famous pioneer installation of a multiple-feed a-c network with manually closed switches at each transformer secondary which would open on reverse energy in case of fault on any of the primary apparatus on the circuit to which the transformer was connected.

While the Seattle installation was in the construction stage a turn of fortune brought across my desk two reports almost simultaneously, containing full technical data on certain new designs of metering equipment. One was a new watt-hour meter for installation on consumer's service, the other was a current transformer for high-voltage metering. With these data, only one evening's work was required to design a multiturn shunt utilizing the iron stampings of the current transformer to which was solidly connected, without intervening "jim-cracks" of any kind, the new watt-hour meter, minus its register. This equipment, built to detailed dimensions by our shop, when delivered to the laboratory and connected with a five kilovolt-ampere transformer gave so much pep on reverse-energy magnetization of the transformer that confidence in my technical training came back to me. Of course the laboratory was unable to determine by direct instrument readings just what was occurring but they did demonstrate that both full-load and short-circuit current values for a 50-kva transformer could be handled satisfactorily with this same relay–shunt combination. Thus a single relaying element had been produced which would handle a 5- or a 50-kva transformer which was our entire range of distribution transformers at the time on radial networks. That was the high-water mark of my career so far as it concerned work on "development of electrical apparatus."

Everything moved rapidly from that time. In a few days simplified shunts, of a type which previously had been reported inadequate, were available for the various sizes of transformers. Meter parts were used for relays. While some of these refinements took place in New York, much of the work was accomplished by G. E. Palmer in Boston. He, more than anyone else, had been responsible for the original proposals being reduced to practice.

Conditions necessary for a successful a-c network to render reliable service at less cost than d-c distribution had been produced at long last and the trial installation with Palmer equipment went into service on Thursday, April 12, 1922.

The Seattle nonautomatic and the New York automatic a-c networks were installations which obtained high reliability of service at reduced cost compared to a competitive d-c system in each case. Shortly after this, Philadelphia, under Chase's guidance, installed a network of somewhat different design to obtain a-c reliability which also has been successful. Those installations succeeded in eliminating the insulation-failure problem so far as reliable a-c distribution service was concerned. Of greater significance, however, they also signaled the start of a harvest of benefits since the change from a-c radial to a-c network distribution affected other elements than the basic one of reliability of service.

The extensive development of such networks after 1922 came about because of reduced costs that are obtained with high-voltage distribution at generated voltage since this arrangement eliminates the usual step-down substation. The production by the electrical manufacturers of suitable distribution transformers made high-voltage distribution practicable. The problem of a universal service on alternating current which was not so simple as it had been with direct current then became a national one with lamp and motor voltages, type of polyphase motors, and metering methods all up for review in many places. It was at this stage that our Manhattan group of Searing, Franklin, Milne, Stuart, and Thomas made full use of years of study that they had given such problems. Bullard, having joined the Electric Bond and Share group of companies under Silver first at New Orleans and then at a number of other cities, and Parker and Woodrow in Brooklyn were all active in the pursuit of reduced costs which were to be realized with high-voltage primaries for network distribution. Each of these men exerted a strong influence in the final stages and out of network developments which were undertaken for economy in a number of cities in rapid succession the three-phase four-wire secondary service emerged as the one generally to be adopted.

I have mentioned only the men whom I know from personal contact to have made outstanding contributions to the end results, and of course have been obliged to omit many names that come to mind. However, I feel that this review today would be very incomplete if I did not list the pioneer work of Fred Hanker, Westinghouse Electric and Manufacturing Company, and Harry Summerhayes, General Electric Company. Both of them, had wonderful insight and expert knowledge relative to the distribution problems of their period. Each contributed in a large measure to orderly progress, particularly in arriving at practicable compromises where the three-phase four-wire service was adopted. I believe that their foresight eliminated numerous difficulties which easily might have occurred in the pioneer installations, particularly in the early use of the combined light and power service. They earned many times over their recognized position of being the wise counselors of utility distribution engineers.

The Westinghouse Company, first of the large manufacturers to enter this equipment field, delivered for the 1924 installation in New York the first automatic network switches that they made. They previously had supplied Seattle with nonautomatic units. The first network papers before this Institute were presented at Chicago, about a fortnight before Lamme's passing on July 8, 1924. I like to think that he was interested in this development as he was in most every other advance in electrical engineering based on the development of electrical apparatus. I know that if he had survived he would have had a great admiration for the group of productive men that I have mentioned and I hope I would have been included in his listing of such a group.

Calculating Antenna Radiation Patterns

RAYMOND W. CRONSHEY
ENROLLED STUDENT

A graphical method of calculating the horizontal relative field patterns of antennas which will handle any number of antenna elements is described. The complexity of the solution is relatively undisturbed by the number of antennas involved, inasmuch as each element is treated separately, and only the final results from all antennas are added.

CALCULATIONS of the horizontal relative field patterns of antennas are long and laborious and increase in complexity with the number of antenna elements employed. Present calculating machines are useful only for antenna-beam arrays consisting of not over three elements. The system described herein will handle any number of antenna elements and can be used to solve problems in a fraction of the time normally required. Its advantages become more apparent as the number of antenna elements increases. The accuracy of these graphical solutions can be made comparable to slide-rule calculations.

There has always been a need for determining the distribution of relative field strength about transmitting antennas, especially where the design or adjustment of the antenna was concerned. Recently, with the utilization of high- and ultra-high-frequency radiation, the improvement of performance resulting from the use of antenna "beams" has been used to advantage. In these applications the horizontal field pattern takes on a greater significance, for it is the shape of this pattern that determines the sharpness or directivity of the radiated beam.

There are two types of horizontal field-strength patterns that may be considered. One is the absolute field-strength pattern which indicates how the intensity of the field varies at different distances from the antenna in any one horizontal plane. The field strength at a point in a certain direction away from the antenna will be different from that at another point in the same direction but at a different distance. This type of field pattern is not of too great importance, and its solution will not be considered in this paper.

The second type of horizontal field-strength pattern is the relative field-strength pattern. It indicates the relative field strength in the horizontal plane in one direction as compared to the field strength in any other direction from the antenna. In it linear distances have no function. This is the important field-strength pattern used for determining the directional qualities of an antenna-beam array. In fact, the shape of this pattern usually is considered to be the shape of the beam. Hereafter, therefore, the words "field-strength pattern" are used in this paper to mean relative field-strength patterns, and any references to field strengths are to be interpreted as being relative field strengths.

Figure 1 shows a sample relative field-strength pattern. These patterns are much like the polar diagrams of light distribution that are used in illumination studies. The radial distance of any point on the curve from the center of the graph is an indication of the field strength in that direction as compared to the field strength in any other direction. The longer the radial lines, the greater is the signal strength indicated.

The normal methods of calculation have seemed adequate for most antenna field-form patterns, because most problems heretofore have involved simple antennas of only two or three elements. It is for the calculation of these relatively simple problems that the accepted mathematical solution can be used to advantage. However, the advent of high-frequency antenna-beam transmission has required the solution of problems involving complex antenna arrays which contain many more than three elements.

The usual communications course in electrical engineering for undergraduate students rarely requires the plotting of more than a half-dozen horizontal field forms. The new ultrahigh-frequency courses promise to include much more work in this line. It stands to reason that for a given number of study hours more patterns can be plotted and more knowledge gained if a faster and simpler system for calculating the field patterns is made available. It can be seen that there is a definite need for this new graphical solution in undergraduate work as well as in industry.

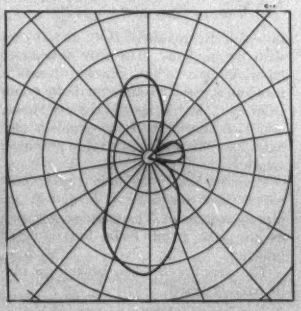


Figure 1. Horizontal field-strength pattern

PRESENT METHODS OF CALCULATION

There are two methods of calculating the field patterns:

1. By mathematical computations.
2. By mechanical means.

The mathematical computations all are based upon the principle given in Figure 2.

Assume two vertical antennas to be located at points A and B. Since the phase of the radiated wave varies (lags) through 360 degrees for every wave length (λ) of linear distance traveled, the phase of the wave from B, relative to A, in the direction of point P would be the initial phase displacement of the currents in the two antennas, θ, plus the phase displacement of the wave as it traveled over distance $\overline{BY}$ to point Y. In other words,

$$\text{Phase}_p = \theta + (d/\lambda)360^\circ \cos\phi$$

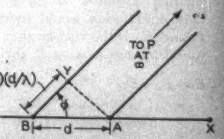


Figure 2. Principle for mathematical computation of field patterns

If some point P in the horizontal plane is chosen, the voltage induced at it will be equal to the vector sum of the two voltages that A and B each would induce in it separately. As point P moves around, describing a circle about the antennas, the variation in amplitude of the induced voltage will indicate definite directional characteristics.

The foregoing equation for phase displacement will hold only when point P

Essential substance of a paper, "A Simple Graphical Method for Calculating Antenna Radiation Patterns," which was awarded the AIEE national prize for Branch paper for the academic year ending June 30, 1943, and the District 5 prize for best Branch paper for 1943. The paper was presented before the AIEE Student Branch at Michigan College of Mining and Technology, Houghton, Mich., January 27, 1943.

Raymond W. Cronshey, a second lieutenant in the United States Army Signal Corps, is currently serving overseas.

is at infinity. However, when point P is far enough distant so that the divergence between the lines $\overline{BP}$ and $\overline{AP}$ is less than four degrees, the lengths of the lines, to all practical purposes, are equal, whether parallel or converging. This condition will be achieved when the distance to point P is over 30 times the spacing between the two antennas. Actually, most receiving antennas are hundreds of times farther away from the transmitters than this, so for all practical purposes the lines

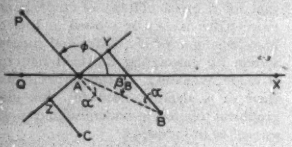


Figure 3

to point P may be considered as being parallel. This is a commonly accepted assumption in antenna calculations.

It will be assumed that point P is far enough away from the antennas so that the lines $\overline{PA}$ and $\overline{PB}$ may be considered parallel. Then the wave from B will lag by $(d/\lambda)\ 360°\cos\phi$ degrees, because of its longer travel, and by θ_B because of the initial phase displacement of the antenna exciting currents. If E_A is the voltage that A radiation would induce at point P, and E_B is the voltage that B radiation would induce at point P, then

$$E_P = E_A + E_B$$

$$E_P = E_A(\cos 0° + j \sin 0°) + E_B \cos[(d/\lambda)360° \cos\phi + \theta] + E_B j \sin[(d/\lambda)360° \cos\phi + \theta]$$

In this case E_A is the reference voltage.

If a larger number of antennas is used, the same sort of reasoning can be applied. When more antenna elements are added, a separate set of sine and cosine terms will have to be added for each antenna considered.

In expressing the difference in phase relationship between the reference voltage, E_A, and any other voltage, E_N, the following parameters will have to be given:

1. ϕ, the direction in which the field strength is to be calculated (azimuth from X).
2. d_N, the distance from the reference antenna to antenna N (measured in wave lengths).
3. β_N, the angle that line $\overline{AN}(d_N)$ makes with $\overline{AX}$.
4. $-\theta_N$, the phase angle by which the exciting current in antenna N lags behind that of antenna A.
5. P_N/P_A, the relative amount of power radiated by antenna N as compared to the power radiated by antenna A. (The voltage induced will be directly proportional to the ratio of radiated powers.)

It can be seen that for any problem in which N antennas are used there are $4(N-1)$ variables. For a four-element array the 12 variables become difficult. For eight elements, the 28 variables make a very clumsy equation. A sample four-element equation would appear as follows:

$$E_P = E_A \sqrt{\begin{aligned}&\{P_B/P_A \cos[\theta_B - 360 d_B \times \\ &\cos(\beta_B - \phi)] + P_C/P_A \times \\ &\cos[\theta_C - 360 d_C \cos(\beta_C - \phi)]\} + \\ &P_D/P_A \cos[\theta_D - 360 d_D \times \\ &\cos(\beta_D - \phi)]\}^2 + \{P_B/P_A \times \\ &\sin[\theta_B - 360 d_B \cos(\beta_B - \phi)] + \\ &P_C/P_A \sin[\theta_C - 360 d_C \cos(\beta_C - \\ &\phi)] + P_D/P_A \sin[\theta_D - 360 d_D \times \\ &\cos(\beta_D - \phi)]\}^2\end{aligned}}$$

Once d_N, β_N, θ_N, and P_N/P_A have been determined, they become fixed quantities. Only ϕ is a variable, but it is incorporated in such a form that not much simplification of the equation results. For each point on the field pattern a new value of ϕ must be chosen and the long process of substitution gone through. When enough points have been plotted on polar-graph paper, the field pattern may be drawn through them.

Only two mechanical methods for calculating the field patterns have been described in technical journals[1] at the writing of this paper. These greatly simplify the labor involved, for they draw the completed field pattern. This carries the simplification to the extreme. However, the maximum number of antenna elements which either of the machines will handle is three. Problems dealing with antenna arrays involving a larger number of elements simply cannot be solved by these machines. It is seen, therefore, that some simpler method is required, especially for arrays with a larger number of elements.

BASIC CONCEPT OF THE GRAPHICAL METHOD

A closer inspection of the sample four-element equation indicates that it is the vector sum of $(N-1)$ quantities broken up into their X and Y components. It is of the form:

$$E_0 = \sqrt{(k_1 \cos B + k_2 \cos C + k_3 \cos D)^2 + (k_1 \sin B + k_2 \sin C + k_3 \sin D)^2}$$

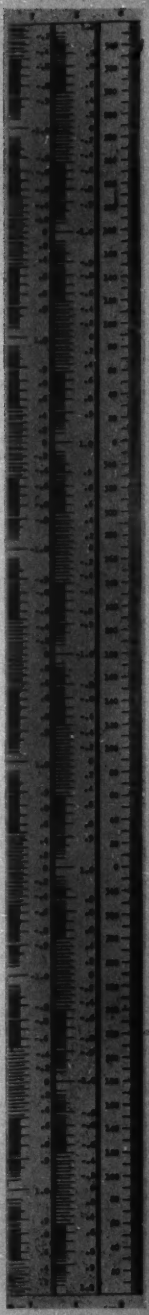
in which the quantities B, C, and D vary with the angle ϕ. The only difficult or laborious part to the solution of such a problem is the determination of the quantities B, C, and D, as the angle ϕ varies, and it is this part of the problem that lends itself admirably to a rapid graphical solution.

Consider the problem in Figure 3 in which three antennas, A, B, and C, are placed as shown. The value of ϕ is such as to place point P in the direction indicated.

The quantity B when broken up into its parts becomes

$$B = \theta_B - 360 d_B \cos(\beta_B - \phi)$$

Figure 4. Linear phasing scale



θ_B is merely a constant from which the rest of the equation will be subtracted. Distance d_B would be a line from A to B. Instead of considering β_B a positive obtuse angle, consider it as a negative acute angle. Then $\cos(\beta_B - \phi)$ becomes $\cos(-\beta_B - \phi)$ or $\cos(\beta_B + \phi)$. Since it is known that $\cos X = -\cos(180° - X)$, then in Figure 3 $\cos(\beta_B + \phi) = -\cos\alpha$.

Thus $360 d_B \cos(\beta_B - \phi)$ becomes $-360 d_B \cos\alpha$. If one looks at Figure 3, it readily can be seen that $d_B \cos\alpha$ is line $\overline{BY}$. The expression for B then becomes

$$B = \theta_B + 360\overline{BY}$$

where the line $\overline{BY}$ is measured in wave lengths and $360\overline{BY}$ converts it into degrees. If line $\overline{BY}$ is measured in degrees instead of wave lengths and θ_B is expressed in degrees, then

$$B = \theta_B + \overline{BY}$$

Similarly,

$$C = \theta_C + \overline{CZ}$$

The problem now has resolved itself into one of expressing the length of a line in degrees of phase lag. In Figure 3 assume that the distance AQ is exactly one wave length long. Let a scale be constructed so that a length AQ will comprise 360 evenly divided spaces. Then each space can be used to represent a degree of phase shift. (The phase shift is -360 degrees for each wave length of linear distance traveled.) In this case, the reference line is one through the reference antenna A and normal to the direction $\overline{AP}$. *In the preceding problem, the distance representing the phase lag ($\overline{BY}$ or $\overline{CZ}$) originates at an antenna and is normal to the reference line.*

To find the quantity B or C directly, lay the evenly divided scale along the line $\overline{BY}$ or $\overline{CZ}$ so that the phase angle of exciting current (θ_B or θ_C) is opposite the point representing the antenna (B or C). Then (with the higher-degree end of the scale in the direction toward the reference line) the scale will cross the reference line at the total value of phase displacement $[(\theta_B + \overline{BY})$ or $(\theta_C + \overline{CZ})]$.

This corresponds to the B and C quantities in the equation:

$$E_\theta = \sqrt{(k_1 \cos B + k_2 \cos C + k_3 \cos D)^2 + (k_1 \sin B + k_2 \sin C + k_3 \sin D)^2}$$

It is now necessary to evaluate $\cos B$ and $\sin B$. To dispense with the use of trigonometrical tables in evaluating them, however, a special linear phasing scale has been devised (see Figure 4). It has three fixed scales; θ, X, and Y. The θ scale is a uniformly divided scale with each division representing a degree of phase lag. This is the "evenly divided scale" previously referred to. The X scale is a cosine scale so arranged as to read opposite each degree on the θ scale the value of the cosine of that angle. The Y scale is a sine scale arranged to read opposite each degree on the θ scale the value of the sine of that angle. In using the linear phasing scale it is not necessary to read the value of the phase lag, but merely the values on the sine and cosine scales. These values are read at the point where the scales cross the reference line (line $\overline{ZAY}$ in Figure 3).

The preceding solution of the problem is merely the solution for one point on the field-pattern curve in the ϕ direction. In order to obtain a sufficient number of points to draw a curve, several values of ϕ must be chosen. This merely means that a new reference line must be drawn through A, normal to the new ϕ direction. The linear phasing scale then can be used to measure the distance from B and C to the new reference lines, and thus data for the new points may be obtained.

REFINEMENTS: THE TANGENTIAL POLAR GRAPH

It will be noticed in Figure 3 that the reference line is located between point P and the antennas B and C. When this is the case $\beta_B < \phi$ and $\beta_C < \phi$; thus the quantity $(\beta_B - \phi)$ is placed in the second or third quadrant. The cosines of such angles are negative, making $B = \theta_B + \overline{BY}$. However, when any antenna (for example, B) is located *between* the reference line and point P, the angle $(\beta_B - \phi)$ lies in

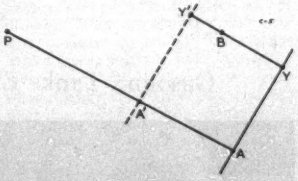


Figure 5. Principle on which tangential polar graph is based

the first or fourth quadrant thus making $B = \theta_B - \overline{BY}$. This would require that the linear phasing scale be turned end for end in measuring line $\overline{BY}$, thus making an angular subtraction instead of an angular addition.

The problem of when to reverse the linear phasing scale and when not to becomes bothersome, and so to eliminate the need for it the tangential polar graph has been devised. Figure 5 illustrates the principle upon which it is based.

Antenna B lies between the reference line and point P. A point A' is chosen such that the distance $\overline{AA'}$ is some integral multiple of a wave length and another reference line $\overline{A'Y'}$ is drawn normal to $\overline{AP}$. Now the new reference line lies between the antenna B and point P, and so the necessity for reversing the linear phasing scale has been eliminated. No inaccuracies will be introduced so long as the distance $\overline{AA'}$ is some integral multiple of a wave length.

It is obvious that, as the direction ϕ varies, the line $\overline{Y'A'}$, of course, will have to move so as always to be normal to $\overline{PA}$. The tangential polar graph takes care of this as shown in Figure 6.

The circle usually can be made one wave length in radius as this will accommodate most problems. At each ten degrees around the circle a tangent has been drawn. These tangents represent the line $\overline{A'Y'}$ in its many positions. Experience has proved that hardly ever is it necessary to plot points closer than ten degrees in order to determine the shape of the field pattern. In fact, only when confronted by sudden changes of shape is it necessary to plot points at intervals any closer than 30 degrees. Consequently the 30-degree tangents are drawn as heavier lines so as to be easily recognized. If it is necessary to resort to ten-degree lines at times, they are included, but only as light lines so as not to add to the confusion. (The crosshatched and the radial lines within the circle are included merely as aids in measuring distances between antennas, and serve no other purpose.)

SAMPLE PROBLEM

Table I lists the conditions of antenna spacing and phase excitation to be used in a sample problem.

With the assistance of the guide lines, four dots can be placed upon the tangential polar graph with a pencil, each dot representing one of the four antennas. This is shown in Figure 7. The information in column 2 can be transferred to the graph by measuring the distances from point A (always at the center of the circle) with the degree scale of the linear phasing scale (one-quarter wave length = 90 degrees, one-half wave length = 180 degrees, and so forth). Assume that one desires to determine E_P in the direction $\phi = 30$ degrees (from line AB). The 30-degree tangent bar then will be used (analogous to line $Y'A'$ in Figure 4).

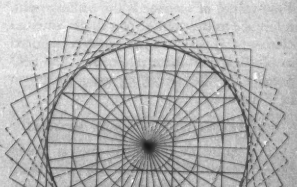


Figure 6. Tangential polar graph

Table I. Conditions of Antenna Spacing and Phase Excitation for Sample Problem

1 Antenna	2 Distance in Wave Lengths	3 Phase Angle of Exciting Current	4 P_N/P_A	5 Displacement (Vertex at A)
A	0	0	1	
B	1/4	56	1	
C	1/2	−20	1	80° from *B*
D	3/4	0	1/2	280° from *B*

Table II

Direction $\phi = 30°$

Antenna	Sin	P_N/P_A Sin	Cos	P_N/P_A Cos
A	0	0	1.0	1.0
B	−0.91	−0.91	−0.43	−0.43
C	−0.99	−0.99	−0.12	−0.12
D	0.88	0.44	0.48	0.24
Total *Y* co-ordinate		−1.46	Total *X* co-ordinate	0.69

Starting with antenna *B* (and remembering that the degrees on the linear phasing scale are angles of *lag*) set the 324-degree mark of the linear phasing scale over point *B* and rotate the scale about point *B* until it (the scale) is normal to the 30-degree tangent. (In all cases the scale should have its high-degree end pointing toward the tangent.) The scale will cross the 30-degree tangent line at cosine = −0.43, and sine = −0.91. Thus the vector voltage that antenna *B* would contribute at point *P* has been broken up conveniently into its *X* and *Y* co-ordinates without any calculations whatsoever. For antenna *C* the scale is set with the 20-degree mark over point *C* and the scale adjusted so as to be normal to the 30-degree tangent. Antenna *C*'s contribution is read as cosine = −0.12, and sine = −0.99. For antenna *D* the scale is set with zero degrees over point *D*, and *D*'s contributing voltage read as cosine = 0.48, and sine = 0.88.

These values are conveniently classified in Table II.

Relative value of induced voltage at point $P = E_P/E_A$

$$E_P/E_A = \sqrt{(0.69)^2 + (1.46)^2} = 1.60$$

This value, of course, is the voltage with reference to the voltage of a single antenna element (*A*) which is just what is required in plotting field-form patterns. The field pattern for the preceding array is shown in Figure 1.

COMPARISON WITH PRESENT METHODS

It is quite evident that this is much easier than substituting 12 variables ($4(N-1) = 12$) into the usual equation and then painstakingly computing the answer. The initial step of placing the dots upon the polar tangential graph should not require over a minute. This is comparable to substituting in the 12 variables (all but ϕ). The second step is the evaluation of the sine and cosine terms and the extraction of their square root. This is comparable to substituting the value of $\phi(30°)2(N-1)$ times into the clumsy equation and then calculating the results.

When it is realized that the foregoing operation must be carried out for every point which is plotted on the field-form pattern, it is quite evident that:

A. The graphical solution has a distinct advantage in that it requires less time.

B. The advantage becomes more and more pronounced as the number of antenna elements increases.

In addition, it might be said that the only calculation required with the graphical method is the computation of the hypotenuse of a right triangle; thus the handling of mathematics and the resulting chances of error are reduced to a minimum.

ACCURACY

It has been found possible, using the actual linear phasing scale and tangential polar graph, to solve problems with sufficient accuracy that the value of the sine and cosine terms could be read to two and many times (at one end of the scale) to three significant figures. It seems entirely possible that, by increasing the size of the graph and the scale, the accuracy can be made even greater. One last advantage that may not have seemed too apparent at first is the fact that both

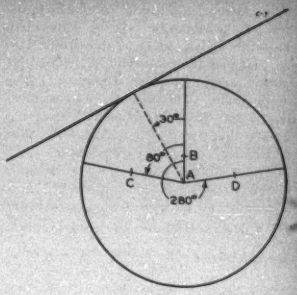


Figure 7

the graph and the scale may be used over and over again. If the points representing antennas are made in pencil, they may be easily erased, leaving the tangential polar graph ready to be used again.

In conclusion, it might be said that with the two simple tools described in this paper, the student and the engineer will be capable of solving the most intricate field-form problems, involving up to an almost infinite number of antenna elements, in a minimum of time and with a minimum amount of effort.

REFERENCE

1. *Proceedings* Institute of Radio Engineers, May 1942.

Gasoline Tanks Electrically Welded

General Electric photo

Electronically controlled resistance welders now seam-weld these detachable gasoline tanks for the Lightning *P*-38 fighters in four minutes at the rate of 60 inches per minute. Since no additional metal is deposited in this process, welding rod ordinarily consumed in rod welding is saved. The process also permits the substitution of steel for the aluminum formerly used. Two of the streamlined tanks are attached like pontoons to the airplanes and, when empty, may be dropped off if the fighter needs to gain speed.

Temperatures Produced by Overloading Oil-Immersed Transformers

E. W. TIPTON
MEMBER AIEE

Power transformers have characteristics that permit the carrying of overloads for short periods of time, provided temperature limitations are not exceeded. The determination of permissible loading is reviewed in this article for the guidance of transformer operators.

TRANSFORMERS have thermal capacity; furthermore, they frequently show lower temperature rises during test than the guaranteed rise. Load factors are usually under 100 per cent and rarely are ambient temperatures continuously 40 degrees centigrade. For these reasons it usually is possible to get out of them more than is indicated by their nameplate ratings.

To illustrate the effect of thermal capacity, consider an ordinary spiral-wound coil made of paper-insulated copper, such as is used in power transformers. In air, it must carry 700 per cent of normal current for five minutes before the paper coating can be charred, but to do the same thing in oil, a much larger current is required. This property makes it possible for transformers to handle extra loads which today are vital to war production.

The load which a transformer can carry is limited by the ability of its insulation to withstand high temperatures. In most cases this insulation consists of cotton, linen, paper, pressboard, varnish, and oil. Many years ago a value of 105 degrees centigrade was established as the upper temperature limit for such materials. This limit still exists in AIEE Standard 1. From this value came the well-known 55-degree-centigrade rise standard for transformers. It was based on the assumption that the hottest spot in the transformer (which cannot be measured conveniently) might be 10 degrees centigrade hotter than the average temperature rise as determined by resistance. The latter quantity is easily measured. Subtraction of this 10-degree-centigrade allowance from the 105-degree-centigrade limiting temperature, with the assumption of a maximum ambient temperature of 40 degrees centigrade (104 degrees Fahrenheit), leaves a permissible temperature rise of 55 degrees centigrade.

The standard method of rating has worked out very well, in general, and transformers so rated have had a satisfactory life. One reason that it has worked so well is that apparently there have been few instances where a free-breathing transformer (which tested right up to the permissible 55-degree-centigrade rise by resistance) has been operated continuously at full rated load with a unity power factor in a steady 40-degree-centigrade ambient temperature. Under such conditions oil would deteriorate quite rapidly. Because of this fact, modern transformers have some means for protecting the oil from oxygen by maintaining an inert atmosphere of nitrogen in contact with the hot oil. Then too, present American Standards specify that average ambient temperature over a 24-hour period should not exceed 30 degrees centigrade, with a maximum at any time of 40 degrees centigrade.

Various standardizing agencies have published a number of guides which tabulate maximum allowable hot-spot temperatures permitted for given periods of time. American Standard C57 permits a continuous hot-spot temperature of 95 degrees centigrade, which experience indicates will give satisfactory life. Also, without appreciable loss of life, recurrent short-time overloads (not oftener than once in 24 hours) and emergency overloads (unexpected overloads of infrequent occurrence) are permitted with temperatures as shown in Table I.

In addition to these limits, certain maximum temperature limits were established in 1942 for emergency overloads that may result in moderate loss of life not to exceed one per cent for each application.[1] These values apply only to modern transformers having adequate means for protecting the oil from oxygen.

Transformer operators may follow the data in Tables I and II or establish other limits which, based on experience, will result in satisfactory operation.

When a method for determining maximum permissible temperature is established, it is necessary, if such information is to be of any value, to be able to calculate what the hot-spot temperature will be after carrying a particular load for a given length of time. Fortunately, formulas for calculating hot-spot temperatures of an oil-insulated transformer are not difficult to use. The temperature of the hottest spot in the winding is made up of three parts: the ambient temperature, the oil temperature rise, and the difference between hot oil and hot copper temperatures (usually called the gradient). This may be written:

$$T_{HS} = T_A + T_O + T_G$$

Overload calculations are based on test results at full rated load and it is assumed that the oil rise varies as the 0.8 power of the total losses, and that the gradient varies as the 0.8 power of the copper loss. These assumptions are not exactly true but they check experimental results very closely. In the form of an equation, this may be written:

$$T_{HS} = T_A + \left[\frac{1 + RL^2}{1 + R}\right]^{0.8} T_O + T_G L^{1.6}$$
$$= T_A + M T_O + T_G L^{1.6}$$

T_{HS} = hot spot copper temperature, degrees centigrade
T_A = ambient temperature, degrees centigrade
T_O = oil rise at full load, degrees centigrade
T_G = gradient at full load, degrees centigrade
L = per unit load
R = ratio of copper loss to iron loss at full load

This formula will give the final temperature of the hottest copper for any load which continues until a temperature balance is reached.

To find temperature at the end of any time t, it is assumed that the temperature of the oil changes (from its value when the

Table I. Temperature Limits for Hottest Spot in Transformer Windings

American Standard C57

Duration, Hours	Degrees Centigrade: Recurrent Overloads	Degrees Centigrade: Emergency Overloads
2	110	115
8	105	110
24	95	105

Table II. Temperature Limits for Hottest Spot in Transformer Windings

AIEE Interim Report on Overloading Transformers

Duration, Hours	Temperature Limit, Deg C
1	137
2	130
4	125
8	120
24	110

E. W. Tipton is transformer engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

load is applied to its final value) according to an exponential law. Also, since the thermal capacity of the copper is relatively small, it is assumed that the gradient reaches its final value at once. This results in only a small error for intervals greater than one-half hour. Ordinarily, in calculations of short-time overloads it is assumed that the transformer has been fully excited but has been carrying no load, or that it has been fully loaded just before the overload is applied.

The general formula for temperature at any time is:

$$T_{HS} = T_A + T_i + (MT_O - T_i)\,(1 - \epsilon^{-t/b}) + T_O L^{1.6}$$

For overloads following no load, this becomes:

$$T_{HS} = T_A + T_O[M + (N - M)\epsilon^{-t/b}] + T_O L^{1.6}$$

And for overloads following full load:

$$T_{HS} = T_A + T_O[M + (1 - M)\epsilon^{-t/b}] + T_O L^{1.6}$$

T_A = oil temperature at start of overload, degrees centigrade

t = time in hours

b = thermal time constant of oil temperature rise

$$N = \left[\frac{1}{1+R}\right]^{0.8}$$

$$M = \left[\frac{1+RL^2}{1+R}\right]^{0.8}$$

These formulas look rather complicated and they do involve fractional powers and exponentials. However, they are reduced to simple multiplication and addition by means of the curves in Figures 1 and 2. In Figure 1, the value of N is plotted as a function of the ratio of copper to iron loss at full load. The value of this ratio is available from the transformer test sheet. Also, on this figure it is possible to read the values of the exponential for any value of t/b, and the value of $L^{1.6}$ for any value of L. Figure 2 gives the value of M for any ratio of losses at various overloads. If it is desired to avoid interpolation, the

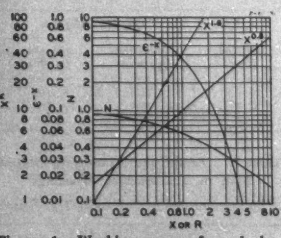


Figure 1. Working curves for calculating overload temperatures

$$N = \left(\frac{1}{1+R}\right)^{0.8}$$

R = ratio copper loss to iron loss at full load

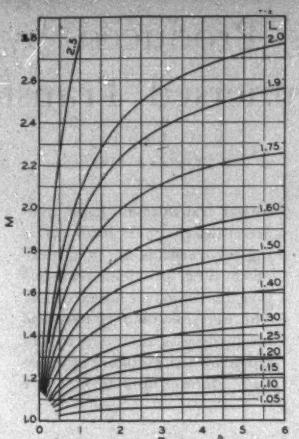


Figure 2. Auxiliary curves for overload temperature calculations

$$M = \left(\frac{1+RL^2}{1+R}\right)^{0.8}$$

R = ratio copper loss to iron loss at full load
L = per unit load

fraction $\frac{1+RL^2}{1+R}$ can be calculated and raised to the 0.8 power by means of the curve on Figure 1.

All data necessary for using this method of calculation are available to the transformer operator. Ambient temperature may be taken from his own records. The ratio of copper to iron loss at full load, the transformer-oil temperature rise at full load, and the gradient at full load can be obtained from the transformer test sheet furnished by the manufacturer. The gradient on the test sheet is the difference between the hot oil and average copper temperatures. To this value must be added a hot-spot allowance which is customarily taken as 10 degrees centigrade although it may frequently be less.

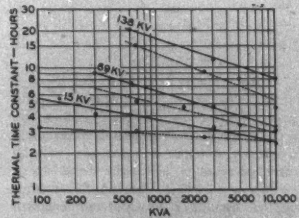


Figure 3. Typical thermal time constants for transformers

Solid lines three phase, dotted lines single phase

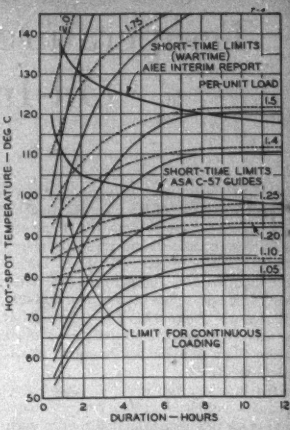


Figure 4. Transformer overload temperature curves for a typical single-phase unit

2,500 kva, 15 kv, time constant 2.66, ambient temperature 15 degrees centigrade, ratio of losses 3.17, gradient 18 degrees centigrade, self-cooled, oil immersed

Solid lines following no load, dotted lines following full load

Transformer time constant is given by the formula:

$$B = \frac{CT_O}{W}$$

B = thermal time constant

W = total watts loss at full load

T_O = oil rise at full load

$$C = \frac{3.5\ (\text{pounds of core and coils} + {}^2/_3\ \text{pounds of tank}) + 12\ (\text{pounds oil})}{60}$$

Of the factors required, watts loss and oil temperature rise can be obtained from the transformer test sheet and weights are engraved on the transformer instruction plate. The thermal time constant is a measure of the time required to heat the materials of which the transformer is built. Figure 3 gives typical values for standard self-cooled oil-immersed transformers. It will be observed that the time constant increases with the voltage class. Operation at higher voltage requires greater insulation clearance and therefore more iron, copper, and oil are required for a given kilovolt-ampere rating. Also, time constant decreases as kilovolt-ampere increases because insulation clearances (which are constant) have less effect on materials required as capacity increases.

Use of calculations (as reviewed before) for determining transformer loading has the advantage that it may be applied to a particular transformer. It permits taking maximum advantage of each favorable factor. Thus, loads are not limited

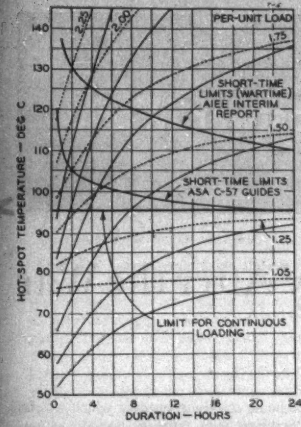


Figure 5. Transformer overload temperature curves for a typical three-phase unit

10,000 kva, 138 kv, time constant 8.1, ambient temperature 15 degrees centigrade, ratio of losses 1.78, gradient 14 degrees centigrade, self-cooled, oil immersed

Solid lines following no load, dotted lines following full load

by considerations that must be applied so as to be safe for the worst possible case in a whole class of designs. One way to utilize the formulas involves plotting a set of overload curves for a particular transformer and superimposing (on this curve) the allowable temperature limits.

Figures 4 and 5 are overload curves for two typical self-cooled transformers. As may be noted, there are two curves each for a number of different overloads—one following no load, the other following full load. Over these curves are plotted a second set of curves showing the temperature limits of the AIEE interim report, the American Standard *C*-57 limits for emergency and recurrent overloads, and also the American Standard *C*-57 limit of 95 degrees centigrade for continuous loads. The temperature limitations are independent of the ambient temperature. The load-temperature curves, however, are dependent directly on the ambient temperature. They are drawn on Figures 4 and 5 for a 15-degree-centigrade ambient temperature. The value of temperature read from these curves must be increased 10 degrees centigrade when the ambient temperature is 25 degrees centigrade or decreased 10 degrees centigrade when the ambient temperature is 5 degrees centigrade. When operating with a 15-degree-centigrade ambient temperature the intersections of the transformer overload curves with the American Standards Association and AIEE temperature-limit curves determine the length of time for which various overloads may be carried without exceeding the standard limiting temperatures.

If the ambient temperature differs from 15 degrees centigrade, then the winding-temperature curves must be replotted if it is desired to read correct values of both winding temperature and safe temperature limits. If, however, it is desired only to find how long a load can be carried without exceeding any given temperature limit a simpler method may be used. Transformer overload curves are plotted for the most convenient ambient temperature, and the standard-temperature-limit curves are plotted on the same sheet. Then, on a transparent curve sheet using the same scales, the AIEE and ASA safe temperature limits are plotted. By placing this second sheet over the first so that the scales coincide, safe values for the ambient temperature selected may be read. For higher ambient temperatures the transparent curve sheet is shifted down an amount equal to the difference between the desired ambient temperature and that for which the overload curves are plotted, and for lower ambient temperatures it is shifted upward.

Curves of Figure 4 are drawn for a single-phase low-voltage transformer which has a time constant of 2.66. It may be noted that the winding temperature approaches its final value at the end of eight hours. Figure 5 is plotted for a three-phase high-voltage transformer which has a time constant of 8.1, nearly three times as great. In this case, it is only after 24 hours that the temperature curves begin to flatten out. Following no load, the single-phase transformer will carry a load of 150 per cent for two hours before reaching a winding temperature of 95 degrees centigrade. The three-phase transformer will carry 150 per cent load for 7.8 hours before reaching the same temperature.

Curves of the type shown in Figures 4 or 5 can be drawn for any transformer and can be used to determine safe loading cycles. In determining safe temperature limits, care must be taken to consider limitations mentioned in the ASA guides for operation and in the AIEE interim report. The values in the interim report apply only to modern transformers having means for protecting the oil—lower limits must be used for older transformers. Capacity of auxiliary apparatus such as tap changers, bushings, reactors, also must be considered. If calculations are carefully made, a large amount of transformer capacity (over and above that shown on transformer rating plates) can be made available.

REFERENCE

1. Interim Report on Guides for Overloading Transformers and Voltage Regulators, AIEE transformer subcommittee. AIEE *Transactions*, volume 61, 1942, September section, pages 692–4.

Calculator Widens Scope of Practical Mathematics

This versatile calculating machine recently was presented by International Business Machines Corporation to Harvard University to be used by the United States Navy for the duration. Employing a unique automatic sequence control which receives problems on a coded tape, the machine will solve practically any known problem to 23 significant figures, including problems involving computation and tabulation of functions, evaluation of integrals, solution of simultaneous linear algebraic equations, and harmonic and statistical analysis. Its basic performance comprises addition, subtraction, use of parentheses and brackets, multiplication, division, interpolation or the location of values of functions in mechanical tables of mathematical functions, card punching of computations, card feeding, and storage of numerical data. Particularly benefited by such calculations are the fields of atomic physics, electronics, actuarial work, optics, and astronomy. The operator of the machine need not be a trained mathematician, but the problem must be coded by one.

This 51-foot calculator contains 500 miles of wire

V. The Electric-Power Industry After the War

T. G. LeCLAIR
FELLOW AIEE

THE plans of the electrical industry, and of the utility industry in particular, for the postwar period are not a new subject. In the utility business where it takes nearly three years to build a new power plant, planning for the future is a routine part of the job. Postwar planning is the same job except that some of the plans must have an *X* date instead of a definite date for beginning construction.

To see what the future holds for us as electrical engineers, we must look at the uses to be made of electricity. This industry includes the manufacturers of equipment as well as the utilities which sell the energy to operate this equipment. At the beginning of the war a number of new developments were about to be put on the market of considerable importance to this industry. Others have been developed during the war period. They cover the entire field including the home, farm, commercial applications, and, last but not least industrial production of both war and peace goods.

The improved electric service in the home, the farm, in commerce, and in industry which will result after the war as an outcome of new developments is discussed in detail. Improved power applications will increase production and decrease labor, predicts this power-company engineer. The conversion problem from wartime to peacetime industry will be much greater than that of the last war, especially for the utilities.

ELECTRICITY IN THE HOME

Let us look first at the possibilities for the electric service in the home. Perhaps one of the most important improvements which can be expected to find a ready acceptance is the home freezer. The quality of frozen food has been improved steadily, and the wartime lessons in the preparation of frozen food will make this much more acceptable. I believe that freezers to keep food in a solid state until needed will become even more popular than the ordinary refrigerator did in the late '20's.

One type of frozen food storage is the basement unit in which fresh foods can be frozen at home. Many of these units are in use in which practically a whole winter's supply of vegetables and meat may be stored. This type of freezing unit is expected to be available both in the form of units for the individual home and multiple units to be placed in the basement storeroom of an apartment building with a locker for each apartment.

Figure 1 illustrates the home freezer combined with the ordinary refrigerator. Some manufacturers have this device now ready to market and consider that it will be more popular than the basement-type freezer. It will be very satisfactory in built-up areas as soon as delivery service is available for frozen foods. The freezing locker in this unit is a relatively smaller compartment underneath the regular food compartment. It will have space for only a few days' supply on the assumption that the food is prepared and delivered in frozen form.

Television is another new development for which there is a popular demand. Just prior to the war a few vision stations had been started, and a number of home television receivers are now in use. Several manufacturers have stated that they can market the home receiver at a reasonable price. Thomas F. Joyce of the Radio Corporation of America recently announced publicly that he believes that television will become a billion-dollar industry shortly after the end of the war. Figure 2 illustrates a postwar design of home television receiver which can be combined with radio to provide an opportunity both to see and to hear a program simultaneously.

The trend toward the completely electrified kitchen was just getting its stride at the beginning of the war and will certainly continue. The modern electric range with its cleanliness, convenience, and safety will be coupled with the new complete refrigerator and the dishwasher.

At the same time home laundry equipment is improving in quality, and the automatic washer is taking more of the drudgery out of doing washing at home. Figure 3 illustrates a laundry combination including a washing machine on the right; a tumbler drier, shown in the center, which dries the clothes with hot air and fluffs them nicely; and a modern pressing machine. This particular washer is not automatic, but automatic washers are now ready to market. Other devices which will make home a more comfortable place in which to live include the modern completely automatic electric range, the electric water heater, the home-cooling unit, and the electronic air cleaner.

These expanded uses of electric service cannot be obtained without solving some problems which engineers will understand. To sell twice as many kilowatt-hours in a home means the use of larger wire and more electric circuits to insure that these appliances will perform in a way that they are intended. As engineers, we must see that all new homes and remodeled homes are provided with adequate wiring, so that new appliances can be installed at a reasonable cost whenever they are purchased.

ELECTRICITY ON THE FARM

In 1943, 40 per cent of the farms in the United States were electrified, and 82 per cent of the farms in Northern Illinois were receiving electric service. The farmer's wife is entitled to the same benefits of electricity for home comforts as the home owner who lives in the city. At the same

Essential substance of an address presented before the Illinois Valley Subsection of the AIEE Urbana Section, in Peoria, Ill., May 18, 1944.

T. G. LeClair is staff engineer with Commonwealth Edison Company, Chicago, Ill.

time electricity has a multitude of other uses on the farm. Figure 4 illustrates one of the many ways in which electricity can save labor by hoisting the hay into the barn. Similar motors can perform a hundred and one other tasks including grinding feed, pumping water, or stirring milk. The shortage of farm labor during the war has taught the farmer much about the dependability of electric service and the savings which it can make in the expense of farm operation.

ELECTRICITY IN THE COMMERCIAL FIELD

In the commercial field fluorescent lighting was just getting its start at the beginning of the war. During the war almost all fluorescent lighting was confined to war plants, because such lighting equipment was on a priority basis. More attractive fixtures and built-in equipment will be the regular practice in the store of the future. Many shops have been closed because of lack of man power and lack of merchandise. When they reopen, each owner will take pride in a modern lighting installation to attract his customers.

Restaurants probably will adopt more electric cooking. This equipment has much to offer in the way of cleanliness and convenience. There are many other applications including the sterilamp to preserve food and the electric precipitator which will take the smallest particle of dirt out of the air that engineers will develop in the next few years.

ELECTRIC POWER IN INDUSTRY

Our biggest wartime lessons in the use of electric power have been learned in the industrial field. War plants have been compelled to use power for production to the maximum extent to replace hand labor with the steadily increasing labor shortage in all industrial areas. It is ridiculous to imagine that these lessons will be forgotten in the period of future civilian production.

In the 20 years from 1919 to 1939 the horsepower per worker in factories nearly doubled. We have no recent statistics, but there is no question that this figure has increased much further. If we are to maintain or raise the American standard of living after the war, we must increase the output per worker of the goods and services which we desire to use. The use of power for more production has given America leisure time for education and pleasure. The use of more power to replace hand labor is the open road toward a still higher standard of living.

One of the best aids to increased production in industry is better lighting. Fluorescent lighting and other forms of gaseous-tube sources have taken a new spurt in the war period. Many civilian factories will certainly be modernized with this form of lighting after the war.

The newest industrial use of electricity with a wide field is the use of high frequency for heating. This high-frequency heating is divided roughly into two classes. One class is used for heating materials which are nonconductors of heat and electricity and is called electrostatic heating. The other class of high-frequency heating is called the induction type where the material is heated by electric current induced in the metal by magnetic field.

Figure 5 illustrates the electrostatic form of heating suitable for rubber, ceramics, plastics, wood, and the like. The high frequency is used to bond sheets of wood together with a plastic material. The

Figure 1 (center). Home freezer combined with ordinary refrigerator

Figure 2 (above). Postwar design of home television receiver which can be combined with radio to provide an opportunity to see and hear a program simultaneously

Figure 3 (top). Laundry combination including (left to right) modern pressing machine, tumbler drier, and washing machine

Figure 4 (above). Electric motor hoisting hay into barn

Figure 5. Electrostatic form of heating suitable for rubber, ceramics, plastics, and wood

alternate sheets of wood and plastic are placed between two electrodes under a mechanical pressure. The application of high frequency to these electrodes generates a uniform heat throughout the wood and plastic, so that the bond can be formed in 12 minutes. With steam heating it took two hours for the heat to penetrate, and the outer layers were overheated before the center was well bonded.

Induction heating is beginning to find a wide variety of uses. Frequencies from 3,000 to 2,000,000 cycles per second have been used for quick brazing and soldering of metals. Equipment to heat heavy shell cases for forging uses still lower frequencies from 60 to 3,000 cycles, depending on the thickness of the structure to be forged. The fact that heat can be concentrated on the part of the structure requiring it makes this method of heating far more economical than any other available form.

The greatest single use of induction heating at the moment is for hardening the surface of steel. By this means heat is concentrated on the surface without warping the structure. The depth of the hardness for a particular application is inversely proportional to the frequency of the induced current.

Welding is another development which has come forward at a very rapid rate during the war period. Welding units use automatic machines to control the speed of welding and the amount of metal deposited during the welding process. Such automatic welding produces a uniform product without blowholes and with a very substantial saving in time. Electric welding undoubtedly will take the place of many other methods for the fabrication of metal products after the war. With the development of the newer alloys, electric welding and brazing are the only practical means by which these new materials can be joined.

CONVERSION FROM WAR TO PEACE

The important problem for postwar planning in the electrical industry is to translate the hundreds of new developments into terms of what we will have to do. The problems of converting this industry or any industry to peacetime conditions require a study of past conditions before we predict what we can expect in the future.

The conversion problem for the whole country is a bigger one than faced us at the end of the last war. The present war already has lasted longer than the World War I, and the United States has been in the war more than a year longer than the total time in the last conflict. This has necessitated a more complete conversion to a wartime economy and will entail a longer road back to civilian life.

Figure 6 illustrates the much greater extent to which we have been on a war basis. In 1918 the war expenditures rose to a maximum of $18,400,000,000 while the national income was $57,000,000,000. In 1943 the war expenditures were $85,000,000,000 and the national income $148,000,000,000. Therefore, the war expenditures instead of being one-third of the national income as in 1918 are now approaching 60 per cent.

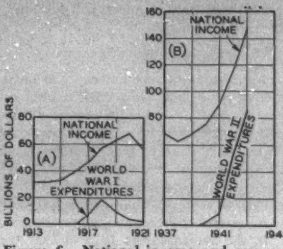


Figure 6. National income and war expenditures

A. Source: E. L. Bogart and National Industrial Conference Board

B. Source: National Industrial Conference Board

The national income in 1943 rose to this high level because of the necessity of war production. Much of this high level has resulted from the temporary employment of homemakers and other marginal workers in industry, as well as from longer working hours. For the postwar period with the reduction in the work week to 40 hours and the return of soldiers, *Fortune* magazine has estimated that the national income should be approximately $138,000,000,000 to maintain prosperity and full employment. The Department of Commerce and other sources have estimated approximately the same figures. Most of this national income will be from civilian pursuits, even though we maintain a larger armed force than in prewar years.

For the utilities the contrast between wars in the conversion problem is even greater, as the amount of power used in industry is coming more and more from utility companies, public and private. Figure 7 illustrates this point by showing the steady increase in the proportion of industrial power which is produced by outside utilities. The lower right-hand chart shows that practically all the increase in the power used in factories since the last war has taken the form of electric motors operating on purchased power. The percentage of power in factories purchased increased from 30 per cent in World War I to 60 per cent in 1940. The upper left-hand chart shows that since 1940, with the sharp increase in war production, the percentage has risen to 70 in 1943.

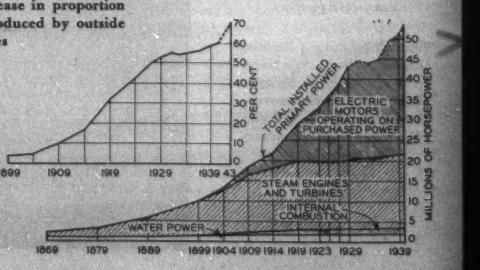


Figure 7. Steady increase in proportion of industrial power produced by outside utilities

A (upper). Percentage of electric motors operating on purchased power

B (lower). Growth in use of factory machinery in the United States

United States Census of manufactures (years between 1929 and 1939 estimated by the Edison Electric Institute)

LOAD ESTIMATES FOR FUTURE TRENDS

In the systems served by the Commonwealth Edison group of companies, the customers are divided into five classes: rural, residential, commercial, industrial, and electric railroads. The kilowatt-hour sales by years to each of these classes are shown in Figure 8. In the ten years from 1933 to 1943, the industrial sales have more than tripled, a large part of this increase being due to the war effort. Rural sales have increased at a tremendous rate, but they do not represent a large proportion of the total. Commercial sales have grown more slowly and have even fallen off in the last two years, because of the inability of small stores and small industries to get materials. The residential load growth has been steady through good times and bad. The supply to electric railroads is neither increasing nor decreasing with the exception of the last two years when there has been some increase because of shortage of gasoline and tires.

It is interesting to speculate what will happen to these various types of load after the war. Those responsible for estimating load trends in Northern Illinois are continually at work sounding out customers as to their plans, and checking and rechecking all conditions which might influence the load in any given classification. The estimated future trends are shown on the right side of Figure 8. It is estimated that with proper sales campaigns, because of the new appliances and devices which will be brought on the market, and for other reasons previously mentioned, the residential load growth is pointed toward a goal of double the 1942 levels at the end of the first five postwar years. In the rural area where about 82 per cent of possible rural customers are now being served, it is expected that the load and the output will more than double. The commercial load is expected to recover promptly to levels higher than at any time in the past as a result of the improvement of business conditions generally, and the fact that money will be available for the purchase of all kinds of material and conveniences

which have been unobtainable during the war. The railroad load which has increased slightly during the war probably will taper off gradually as gasoline and tires for automobiles become available for transportation to and from work. The industrial load probably will drop back nearly to the 1940 level and from there on again will begin to rise. Just how fast these loads will change after the war will depend, of course, on the manner in which the war ends. Consequently, in all these charts a space has been left after 1943 which should indicate first, that we do not know when the war will end and, second, that we do not know how it will end; consequently, we cannot predict the shape of the curve in this uncertain period.

Many estimates have been made by representatives of utilities in various parts of the country. These estimates differ because estimators differ on future general business conditions, and, to a much greater degree, because of the local conditions in the area served. Those areas with strictly war plants, such as shipbuilding and airplane manufacture, undoubtedly have the greatest future problem. Nonindustrial areas probably will have less of a conversion problem for the utility. You may be interested in a few of the preliminary estimates made by representative utilities as to what their maximum demand will be after the war. In Figure 9 the peak load for 1943–44 is used as 100 per cent, and the estimated demand at the end of the first full calendar year after the close of the war is the first point of the prediction. The most optimistic estimate shows a load in the first postwar year 13.5 per cent higher than the 1943 peak. The most pessimistic expects that at the end of the third year after the war the recovery will have reached only 94 per cent. These maximum-demand estimates all are greater than the predicted increase in kilowatt-hours, because the change from war time to standard time has been estimated to increase the national demand as much as 1,500,000 kilowatts, and may increase the demand in the Chicago area by 70,000 to 100,000 kilowatts.

The picture for the Commonwealth Edison group of companies might be considered representative of many other areas, because this territory includes everything from the densely populated city of Chicago to a large rural area. The predicted rates of load growth by classes have been translated to an estimated rate of load growth for the total system as shown in Figure 10. It will be noted that this prediction shows the total system load coming back to the present levels in about the third year after the end of the war. Some utility operators who have seen this estimate consider it optimistic, but we believe it is based on the study of conditions such that it is perfectly attainable. With anything like good business conditions there is no reason why this goal cannot be attained.

The electric-power industry has a special opportunity to help provide continued prosperity and improved living in the future in the United States. In so doing, that industry will offer a multitude of opportunities for engineering work in many new and interesting fields as well as in present fields. The term "electric-power industry" is used in its broader meaning to include the manufacturer of electric equipment; the utility which supplies the power to the users; and the utilization of electric power for an increasing number of services in industries, farms, homes, and elsewhere. The entire power industry is only scratching the surface of the problems which require engineering talent.

EFFECT OF NEW DEVELOPMENTS

In the electric utilities field there are many new developments which will affect our engineering in the postwar period. For example, we must study the developments on insulations that withstand extra high temperatures to see what savings in materials can be made by their application. Noninflammable transformers and air circuit breakers are available, but full use of these new developments has not yet been made in saving the cost of protective enclosures. The reliability of modern equipment and installations is such that we should make every effort to simplify designs all the way from the generating station through the system to the customers' meters. By these improvements in plans we can give equal service with decreased cost and can have a system which is more flexible to provide for unexpected load growth.

There is some possibility that efficient and relatively inexpensive sources of power may be available in small units. We must be alert to use these small power sources for special power plants or for application at remote parts of the distribution system to insure that the industry continues to supply the most efficient brand of service from whatever source feasible.

In industry we must continue to apply the lessons which have been learned during the war period in radio, radar, high-frequency heating, improved lighting, and use of power. Electronic controls and other improvements in power applications will do much to increase production with a decrease in labor. In fact, in this field we can expect engineers to continue the trend of increasing the power used per worker to make further advances in the American standard of living, thereby giving us more comforts with the same labor.

For the home and for the farm, new, improved, and more efficient appliances must be developed and marketed, and much work is to be done in providing adequate and attractive lighting. Labor saving and comfort in the home are as important as labor saving in the industry.

Last but not least in this world that is becoming more and more affected by technological developments, we as engineers must learn to increase the application of our analytical abilities to the fields of management, and in this direction lie many opportunities.

There is an open door ahead, and I believe there is a renewed opportunity for a long and useful career for engineers in the electric-power industry when peace comes.

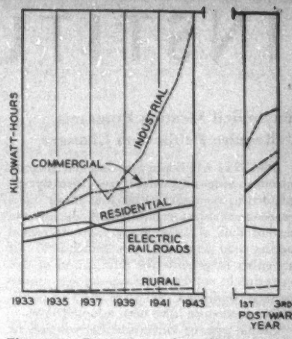


Figure 8. Past sales and predicted future sales to customer classes in Commonwealth Edison group of companies

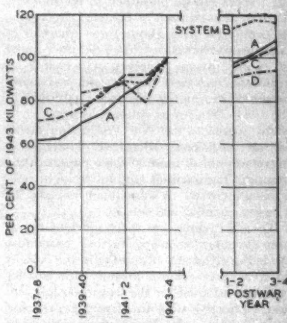


Figure 9. Past system peak loads and predicted future peak loads of Commonwealth Edison group

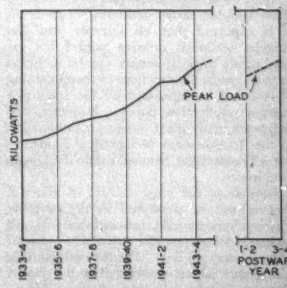


Figure 10. Past peak loads and predicted future peak loads of typical systems in relation to 1943 loads

INSTITUTE ACTIVITIES

Expanded Meeting Programs Require Publication Changes

The 1944 AIEE summer and Los Angeles meeting programs, which were greatly expanded to meet current wartime needs, have made available for publication during the second half of 1944 many more technical papers than originally were anticipated. In an effort to provide for publication of this material in an appropriate manner under present conditions, certain changes in publication procedure have been adopted.

Under present Governmental restrictions on the use of "magazine" paper, it is estimated that less than half of the total pages of the summer and Los Angeles technical meeting papers can be published in the monthly Transactions sections of *Electrical Engineering*, as compared with about three quarters in previous recent years. The Institute's quota of "book" paper, however, will enable all approved technical papers and discussions presented during the year to be published in the 1944 *Transactions* volume, as usual.

An appeal to the War Production Board for an additional allotment of magazine paper to publish more of these papers in the monthly Transactions sections brought only a token increase. A subsequent reappeal for a larger quantity was denied.

To make somewhat more efficient use of present paper tonnage, further economies are being effected. Beginning in the August issue, a three-column format with smaller type was adopted for the feature-article section. Effective with this issue, the spacing between lines in the Transactions section has been reduced. In addition, a lighter-weight paper will be used as soon as the present supply is exhausted.

With these new economies, in addition to those adopted earlier (*EE Jan '44 pp 24–5*), it is expected that all summer and Los Angeles technical meeting papers not exceeding six pages in length can be included in the Transactions sections of the remaining 1944 issues, as stipulated by the Institute's current publication policy. However, this will leave many more papers for publication in the "Supplement to Electrical Engineering—Transactions Section" than had been anticipated.

Because of the large amount of material that cannot be published in the monthly Transactions sections, two supplements will be issued for the second half of 1944 instead of the customary one. The first will contain the longer papers presented at the North Eastern District meeting, Boston, Mass., April 19–20, and at the summer technical meeting, St. Louis, Mo., June 26–30, plus all approved discussions of all papers presented at these two meetings. The second supplement will include the longer Los Angeles meeting papers and all approved discussions of all Los Angeles meeting papers. The first supplement will be issued as soon as the material involved can be released and prepared for publication; the second as soon after the close of the year as possible.

As announced periodically, the supplements are produced in a limited edition on an advance-order basis at 50 cents per copy. Further details as to the contents of these two supplements will be announced later.

Future AIEE Meetings

Winter Technical Meeting
New York, N. Y., January 22–26, 1945

North Eastern District Meeting
Buffalo, N. Y., Spring 1945

Summer Technical Meeting
Detroit, Mich., June 25–29, 1945

Lamme Medal Nominations

Attention is called again to the opportunity open to any Institute member to submit nominations for the 1944 AIEE Lamme Medal. All nominations must be received not later than December 1. For further particulars see *Electrical Engineering*, June 1944, page 225.

The 1943 medal was awarded to Arthur H. Kehoe, vice-president of the Consolidated Edison Company of New York, Inc., New York, N. Y. Addresses delivered at the presentation ceremonies are published in this issue of *Electrical Engineering*, pages 327–30.

PERSONAL ••••

E. T. Augustine (A '27, M '33) formerly district engineer in the western division of the Western Massachusetts Electric Company, Pittsfield, has been appointed assistant chief engineer of the company with his office in Springfield, Mass. Mr. Augustine was graduated from the Thomas S. Clarkson Memorial College of Technology in 1924 with the degree of bachelor of science in electrical engineering. He received the degree of master of science in electrical engineering in 1926 and the professional degree of electrical engineer in 1928. Mr. Augustine became associated with the Western Massachusetts Company, Springfield, Mass. as system planning engineer in 1929. In 1932, he was transferred to Pittsfield as district engineer for the Pittsfield Electric Company, which later became the western division of the Western Massachusetts Electric Company.

G. H. Stickney (A '04, F '24) retired consulting illuminating engineer of the General Electric Company has been awarded the Illuminating Engineering Society Gold Medal in recognition of "meritorious achievement which has conspicuously furthered the profession, art, or knowledge of illuminating engineering." Mr. Stickney was assistant commercial engineer in the General Electric Company, Lynn (Mass.) works, from 1898 to 1909. He was employed in the company's Schenectady (N. Y.) works until 1911 when he was transferred to the Edison lamp works, Harrison, N. J. From 1930 to 1937 he was consulting engineer for the Nela Park engineering division, Cleveland, Ohio. He retired in 1937 to Daytona Beach, Fla.

H. B. Gear (A '01, F '20) vice-president in charge of operating and engineering, Commonwealth Edison Company, Chicago, Ill., retired recently. Born in Marietta, Ohio, March 6, 1872, Mr. Gear received the degree of bachelor of arts from Marietta College in 1892 and the degree of mechanical engineer from Cornell University in 1895. He joined the Commonwealth Edison Company in 1895 as an electrical inspector and he was engineer of distribution from 1911 to 1921. From 1921 to 1936 he was assistant to the vice-president in charge of engineering, construction, and operation. Mr. Gear was elected vice-president in 1936.

G. L. Harvey (Enrolled Student) engineer, Kellex Engineering Corporation, Oak Ridge, Tenn., has been awarded the 1943 District 6 prize award for Branch paper as coauthor of the paper, "A Two-Speed A-C Generator." Mr. Harvey was born in Denver, Colo., October 18, 1922. He received the degree of bachelor of science in electrical engineering from the University of Denver in 1943, and in that year he was chairman of the university's AIEE Student Branch. In 1943 he was employed as a test engineer by the General Electric Company, Denver, and was placed on leave of absence in 1944 to work with the Kellex Engineering Corporation.

F. T. Hague (A '14) formerly manager of engineering, steam division, Westinghouse Electric and Manufacturing Company, Lester, Pa., has been appointed assistant to the vice-president. Mr. Hague will serve as engineering consultant for all departments of the division. He has been with the company since his graduation from the University of Pittsburgh in 1911 with the degree of bachelor of science in electrical engineering.

M. H. Hobbs (M '37) formerly manager, switchboard engineering, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed manager of the engineering department of the division. Mr. Hobbs has been employed by the Westinghouse Company since 1922. He was a section engineer in the metal-clad switchgear section from 1925 to 1936 and was promoted to manager of switchboard engineering in 1936.

F. E. Bodine (A '43) formerly manager, Salt Lake City (Utah) office, Westinghouse Electric and Manufacturing Company, has been made manager of the company's San Francisco, Calif., office. Mr. Bodine has been in the employ of the Westinghouse Company since his graduation with the degree of bachelor of science in electrical engineering from Colorado State College in 1926.

OBITUARY

William Charles Louttit (M '31) assistant works manager, plastics division, Canadian Industries, Ltd., Brownsburg, Que., Canada, died July 9, 1944. Mr. Louttit, who was born in Kirkwall, Orkney, Scotland, July 17, 1895, received the degree of bachelor of science in electrical engineering from McGill University in 1921. He was employed as tester by the Imperial Wire and Cable Company, Montreal, Que., Canada, in 1912 and 1913. In 1913 he was employed by Mackenzie Mann and Company, on work for the Canadian National Railways, Montreal, as a battery charger and repairman. He left the company in 1915 to become affiliated with the Steel Company of Canada, Montreal, as a machine hand, but he returned to Mackenzie Mann and Company in 1916 as electrician. In 1920 he was employed as electrician in the Northern Electric Company, Montreal. He was employed by the Industrial Electric Company, Havana, Cuba, as electrical engineer from 1921 to 1922. In 1922 he became associated with the Havana Central Railroad, now known as the United Railways of Havana, as office engineer. He was made assistant chief electrical engineer in 1927 and became chief electrical engineer in 1928. Mr. Louttit received a commission in World War I and was a pilot in the Royal Air Force.

William J. Mowbray (A '03, M '12, F '31) instructor in electrical engineering, Rhode Island State College, Kingston, died July 4, 1944. Mr. Mowbray was born February 7, 1876, in Drumholm, Ireland. He was employed by the Edison Electric Illuminating Company of Brooklyn (N. Y.) from 1893 until 1905. In 1906, he became associated with the Narragansett Electric Lighting Company of Providence, R. I., and was in charge of distribution. From 1911 to 1918 he was in charge of the electrical laboratory. He was research and test engineer as well as educational director for the company from 1919 to 1930. During his employment, he invented the Mowbray test meter which is used for testing watt-hour meters. In 1932 he joined the faculty of Rhode Island State College. Mr. Mowbray was a member of the AIEE instruments and measurements committee from 1924 to 1929, and he served as a member of the executive committee from 1927 to 1932. He was the author of a number of technical papers.

Robert David Price (A '44) associate engineer, Newark (N. J.) Signal Corps inspection zone, died June 24, 1944. Born in Brooklyn, N. Y., March 6, 1917, Mr. Price was graduated from Polytechnic Institute of Brooklyn with the degree of bachelor of electrical engineering in 1938. He was employed by the Public Service Electric and Gas Company of New Jersey, Newark, as a cable inspector in 1937. In 1938 he was employed as an engineer for the Department of Public Works, New York, N. Y., and John A. Roebling's Sons Company, Trenton, N. J. From 1939 to 1940 he was associated with the American Transformer Company, Newark, N. J., as a test engineer. He was an inspector with the Navy Department, office of inspector of naval materials, Schenectady, N. Y., from 1940 to 1941. He had been employed as an associate engineer in the Newark Signal Corps inspection zone since 1941.

Douglas A. Elliott (A '28) lieutenant commander, United States Naval Reserve, died July 31, 1944. Commander Elliott was born June 14, 1893, in New York, N. Y. He was graduated from Princeton University with the degree of bachelor of literature in 1915 and received his electrical engineering degree from Columbia University in 1928. He was employed by the Electrical Research Products, Inc., New York, as district service supervisor in 1929. In 1931 he became installation planning supervisor for the company. He later joined the communications department of the Radio Corporation of America, New York. In 1942 he received his commission as lieutenant commander in the United States Naval Reserve and became naval advisor to the War Production Board, New York. He was transferred to Rochester, N. Y., in the same capacity in 1943. In 1944 he was made field officer for the industry cooperation division, Syracuse, N. Y.

Charles Ernest Cansfield (A '25) president, Cansfield Electrical Works, Ltd., Toronto, Ont., Canada, died July 23, 1944. He was born December 6, 1884, in York, England. From 1901 to 1906 he was employed by the North Eastern Railroad, York, as an apprentice electrical engineer. In 1906 he joined the York City Corporation as a junior engineer. He became a meter tester in the employ of the Toronto Electric Light Company in 1908. From 1919 to 1921 he was associated with the Toronto and Niagara Power Company as a relay engineer. He founded the Cansfield Electrical Works in 1921.

MEMBERSHIP

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the national secretary before September 30, 1944, or November 30, 1944, if the applicant resides outside of the United States or Canada.

To Grade of Member

Blumberg, R. D., Consulting Engr., Houston, Texas
Caswell, B. H., Sangamo Weston, Ltd., Wolverhampton, England
Coon, I. F. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Elsey, H. M., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Formhals, W. H. (Reelection), Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Gray, K. (Reelection), Ward Leonard Elec. Co., Chicago, Ill.
Hooker, T., Delaware Pr. & Lt. Co., Wilmington, Del.
Jordan, C. E., H. A. Kuljian & Co., Philadelphia, Pa.
Knoeppel, F. W. (Reelection), U. S. Naval Air Station, Richmond, Fla.
Larson, R. W., Radio Corp. of America, Lancaster, Pa.
Lee, J. H., Ohio Midland Lt. & Pr. Co., Canal Winchester, Ohio
MacLean, W. R., Polytechnic Inst. of Brooklyn, Brooklyn, N. Y.
Manuele, J., Jr. (Reelection), Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Mock, R. M., Lear, Inc., Piqua, Ohio
Pennybacker, M. W., I-T-E Circuit Breaker Co., Philadelphia, Pa.
Pierson, F., Stafford, Davies & Gogerty, Inyokern, Calif.
Renne, H. S., "Radio News & Radio-Electronic Engg.," Chicago, Ill.
Richardson, C. L. (Reelection), Captain, R.C.C.S., Toronto, Ont., Can.
Sama, C. M., Dharampur State, Bombay, India
Sparling, W. S., Ohio Bell Tel. Co., Cleveland, Ohio
Wortman, H. H., S.W. Bell Tel. Co., Oklahoma City, Okla.

21 to grade of Member

To Grade of Associate

United States and Canada

1. NORTH EASTERN

Chermak, R. M., Gen. Elec. Co., Schenectady, N. Y.
Hart, R. D., Univ. of Conn., Storrs, Conn.
Hubert, E. F., J. J. Costello Co., Boston, Mass.
Sauer, A. W., Bethlehem Steel Corp., Lackawanna, N. Y.

2. MIDDLE EASTERN

Gibson, D. L., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Moore, L. B., Grimes Mfg. Co., Urbana, Ohio
Muszynski, S., Duquesne Light Co., Pittsburgh, Pa.
Richardson, D. C., Celanese Corp. of America, Cumberland, Md.
Sherrard, J. O., National Elec. Coil Co., Columbus, Ohio
Turner, E. R., Trumbull Elec. Mfg. Co., Norwood, Ohio
Vaughan, J. T., Ohio Crankshaft Co., Cleveland, Ohio
Weil, C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Williams, R. B., Gen. Elec. Co., Baltimore, Md.

3. NEW YORK CITY

Coleman, H. S., Gen. Cable Corp., Perth Amboy, N. J.
Esteve, C. A., El Indicador Industrial, New York, N. Y.
Gillespie, C. N., R.C.A. Laboratories, New York, N. Y.
Goertz, R. C., Sperry Gyroscope Co., Garden City, N. Y.
Henderickson, H. S., Sperry Gyroscope Co., Inc., Garden City, N. Y.
Tinsley, W. E., Sperry Gyroscope Co., Inc., Great Neck, N. Y.
Weiner, J. R., R.C.A. Laboratories, New York, N. Y.

4. SOUTHERN

Cogburn, C. W., Florida Pr. & Lt. Co., Fort Pierce, Fla.
Duncan, W. E., Tenn. Valley Auth., Chattanooga, Tenn.

5. GREAT LAKES

Arnold, W. C., Central Ill. Light Co., Princeville, Ill.
Cartwright, P. A., Univ. of Minn., Minneapolis, Minn.
Frank, C. W., Automatic Elec. Co., Chicago, Ill.
Grabbe, G. M., Gen. Motors Corp., Indianapolis, Ind.
Hunter, O. L., Chicago Bridge & Iron Co., Seneca, Ill.
Jackson, B., USAAF Matériel Command, Minneapolis, Minn.
Jones, G. L., Kinney Elec. Mfg. Co., Chicago, Ill.
Kauppi, T. A., Dow Corning Corp., Midland, Mich.
Klenze, R. O. (Reelection), Acme Steel Co., Chicago, Ill.
Langford, M. H., Dow Magnesium Corp., Marysville, Mich.
Nelson, C. O., Radio Corp. of America, Indianapolis, Ind.
Stansback, H. I., Jr., Square D Co., Milwaukee, Wis.
Timerman, A. T., Schweitzer & Conrad, Inc., Chicago, Ill.

7. SOUTH WEST

Brooks, F. E., Jr., Univ. of Texas, Austin, Texas
Peterson, F. W., St. Louis Shipbuilding & Steel Co., St. Louis, Mo.
Walsh, C. H., Arkansas Pr. & Lt. Co., Pine Bluff, Ark.

8. PACIFIC

Ansell, R. J., U. S. Navy, San Francisco, Calif.
Begovich, N. A., Calif. Inst. of Tech., Pasadena, Calif.
Dinapoli, D. P. (Reelection), Pacific Gas & Elec. Co., San Francisco, Calif.
Hassell, P. A., Chief Radio Technician, U. S. Navy, San Francisco, Calif.
Kahn, L. P., Douglas Aircraft Co., Inc., Long Beach, Calif.
McClure, J. L., Allis-Chalmers Mfg. Co., San Francisco, Calif.
Reimers, J. M., Marinship Corp., Sausalito, Calif.
Ryall, E. W., Douglas Aircraft Co., Inc., Santa Monica, Calif.
Simonoff, A. A., Moore Dry Dock Co., Oakland, Calif.
Wissbaum, J. D., Bethlehem Steel Co., San Francisco, Calif.

9. NORTH WEST

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M. B. Wyman

Institute Representatives

Alfred Noble Prize Committee, ASCE
Robin Beach

American Association for the Advancement of Science, Council
T. H. Morgan — I. Melville Stein

American Committee on Marking of Obstructions to Air Navigation
G. E. Dean — H. L. Huber

American Coordinating Committee on Corrosion
H. S. Phelps — E. B. King, *alternate*

American Research Committee on Grounding
C. T. Sinclair

American Standards Association, Standards Council
R. T. Henry — J. R. North — H. S. Osborne
Alternates
H. E. Farrer — H. L. Huber — E. B. Paxton

American Standards Association, Board of Directors
J. T. Barron

American Year Book, Advisory Board
H. H. Henline

Committee of Apparatus Makers and Users, NRC
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Charles A. Coffin Fellowship and Research Fund Committee
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Construction Industries Advisory Committee War Production Board
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John Castlereagh Parker

Electrical Standards Committee, ASA
H. L. Huber — A. C. Monteith — J. R. North
Alternates
H. E. Farrer — E. L. Moreland — E. B. Paxton

Engineering Foundation Board
F. M. Farmer — W. I. Slichter

Engineering Societies Monographs Committee
F. M. Farmer — W. I. Slichter

(*Continued on next page*)

Geographical District Executive Committees

District	Chairman (Vice-President, AIEE)	Secretary (District Secretary)	Chairman, District Committee on Student Activities
1 North Eastern	R. T. Henry, 303 Electric Bldg., Buffalo, N. Y.	Victor Siegfried, Worcester Polytechnic Institute, Worcester, Mass.	R. G. Porter, Northeastern University, Boston, Mass.
2 Middle Eastern	W. E. Wickenden, Case School of Applied Science, Cleveland 6, Ohio	H. R. Vaughan, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.	P. X. Rice, Pennsylvania State College, State College, Pa.
3 New York City	J. F. Fairman, Consolidated Edison Co. of New York, Inc., 4 Irving Place, New York 3, N. Y.	C. S. Purnell, Westinghouse Elec. & Mfg. Co., 40 Wall St., New York 5, N. Y.	D. H. Wright, Pratt Institute, Brooklyn, N. Y.
4 Southern	C. W. Ricker, Tulane University, New Orleans, La.	F. E. Johnson, Jr., 317 Baronne St., New Orleans 9, La.	W. O. Leffell, University of Tennessee, Knoxville, Tenn.
5 Great Lakes	M. S. Coover, Iowa State College, Ames, Iowa	N. C. Pearcy, Public Utility Engg. & Service Corp., 231 S. LaSalle St., Chicago 4, Ill.	M. M. Cory, Michigan State College, East Lansing, Mich.
6 North Central	L. A. Bingham, University of Colorado, Boulder, Colo.	Platt Wicks, University of Colorado, Boulder, Colo.	O. E. Edison, University of Nebraska, Lincoln, Nebr.
7 South West	R. W. Warner, University of Texas, Austin, Tex.	S. R. Friedsam, 3612 Bonnie Road, Austin, Tex.	M. C. Hughes, A. & M. College of Texas, College Station, Tex.
8 Pacific	J. M. Gaylord, Metropolitan Water District of Southern California, 306 W. Third St., Los Angeles 13, Calif.	Mark A. Sawyer, Box 5300, Metropolitan Station, Los Angeles, Calif.	F. W. Maxstadt, California Institute of Technology, Pasadena, Calif.
9 North West	C. B. Carpenter, Pacific Tel. & Tel. Co., 730 S.E. Oak St., Portland, Ore.	C. C. Bosler, Westinghouse Elec. & Mfg. Co., 309 S.W. Sixth Ave., Portland 4, Ore.	L. D. Harris, University of Utah, Salt Lake City, Utah
10 Canada	Walter J. Gilson, 1244 Dufferin St., Toronto, Ont.	W. Roy Harmer, H.E.P.C. of Ontario, 620 University Ave., Toronto, Ont.	

Each District executive committee includes also the chairmen and secretaries of all Sections within the District, and the District vice-chairman of the national membership committee.

Engineering Societies Personnel Service, Inc.
H. H. Henline

Engineers' Council for Professional Development
O. W. Eshbach J. F. Fairman Everett S. Lee

Hertz Award Committee
M. S. Coover

Hoover Medal Board of Award
H. H. Barnes, Jr. F. M. Farmer John C. Parker

John Fritz Medal Board of Award
Nevin E. Funk David C. Prince
H. S. Osborne R. W. Sorensen

Joint Conference Committee of Founder Societies and A.I.Ch.E.
N. E. Funk H. H. Henline C. A. Powel

Library Board, United Engineering Trustees, Inc.
W. A. Del Mar G. L. Knight
H. H. Henline W. I. Slichter

Marston Medal Board of Award
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National Bureau of Engineering Registration, Advisory Board
C. R. Beardsley

National Fire Protection Association, Electrical Committee
W. Ralph Smith F. V. Magalhaes, *alternate*

National Fire Waste Council
Wills Maclachlan W. Ralph Smith

National Research Council, Division of Engineering and Industrial Research
R. W. Sorensen

Quarterly of Applied Mathematics
J. G. Brainerd

Radio Technical Planning Board
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Research Procedure Committee, Engineering Foundation
W. A. Lewis

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H. L. Huber A. C. Monteith J. R. North
Alternates
H. E. Farrer E. L. Moreland E. B. Paxton

Washington Award Commission
H. B. Gear L. R. Mapes

World Power Conference, Executive Committee of U. S. National Committee
C. A. Powel

General Counsel

Parker & Aaron, 55 Liberty Street, New York 5, N. Y.

Student Branches of the Institute

Name and Location	District	Counselor (Member of Faculty)
Akron, Univ. of, Akron, Ohio	2	A. J. B. Fairburn
Alabama Polytechnic Inst., Auburn	4	
Alabama, Univ. of, University	4	W. J. Miller
Alberta, Univ. of, Edmonton, Can.	10	R. E. Phillips
Arizona, Univ. of, Tucson	8	J. C. Clark
Arkansas, Univ. of, Fayetteville	7	W. B. Stelzner
British Columbia, Univ. of, Vancouver, Can.	10	W. B. Coulthard
Brooklyn, Polytechnic Inst. of, Brooklyn, N. Y.	3	A. B. Giordano
Brown Univ., Providence, R. I.	1	F. N. Tompkins
Bucknell Univ., Lewisburg, Pa.	2	K. B. MacKichan
Calif. Inst. of Tech., Pasadena	8	F. W. Maxstadt
Calif., Univ. of, Berkeley	8	P. L. Morton
Carnegie Inst. of Tech., Pittsburgh, Pa.	2	G. R. Patterson
Case School of Applied Science, Cleveland, Ohio	2	P. L. Hoover
Catholic Univ. of America, Washington, D. C.	2	T. J. MacKavanagh
Cincinnati, Univ. of, Cincinnati, Ohio	2	
Clarkson College of Technology, Potsdam, N. Y.	1	A. R. Powers
Clemson Agricultural College, Clemson, S. C.	4	F. T. Tingley
Colorado State Col. of A. & M. Arts, Fort Collins	6	F. B. Beatty
Colorado, Univ. of, Boulder	6	H. B. Palmer
Columbia Univ., New York, N. Y.	3	J. R. Ragazzini
Connecticut, Univ. of, Storrs	1	P. H. Nelson
Cooper Union, New York, N. Y.	3	E. E. Shelton
Cornell Univ., Ithaca, N. Y.	1	E. T. B. Gross
Delaware, Univ. of, Newark, Del.	2	M. G. Young
Denver, Univ. of, Denver, Colo.	6	F. H. McClain
Detroit, Univ. of, Detroit, Mich.	5	H. O. Warner
Drexel Inst. of Technology, Philadelphia, Pa.	2	E. O. Lange
Duke Univ., Durham, N. C.	4	Otto Meier, Jr.
Florida, Univ. of, Gainesville	4	E. F. Smith
George Washington Univ., Washington, D. C.	2	
Georgia School of Technology, Atlanta	4	H. B. Duling
Harvard Univ., Cambridge, Mass.	1	J. D. Cobine
Idaho, Univ. of, Moscow	9	J. Hugo Johnson
Illinois Inst. of Technology, Chicago	5	E. H. Freeman
Illinois, Univ. of, Urbana	5	E. A. Reid
Iowa State Col., Ames	5	B. S. Willis
Iowa, Univ. of, Iowa City	5	H. R. Reed
Johns Hopkins Univ., Baltimore, Md.	2	M. W. Pullen
Kansas State Col., Manhattan	7	R. G. Kloeffler
Kansas, Univ. of, Lawrence	7	G. A. Richardson
Kentucky, Univ. of, Lexington	4	Brinkley Barnett
Lafayette Col., Easton, Pa.	2	F. W. Smith
Lehigh Univ., Bethlehem, Pa.	2	C. G. Brennecke
Louisiana State Univ., Baton Rouge	4	A. K. Ramsey
Louisville, Univ. of, Louisville, Ky.	4	S. T. Fife
Maine, Univ. of, Orono	1	W. J. Creamer
Manhattan Col., New York, N. Y.	3	R. T. Weil
Marquette Univ., Milwaukee, Wis.	5	J. F. H. Douglas
Maryland, Univ. of, College Park	2	L. J. Hodgins
Mass. Inst. of Technology, Cambridge 39	1	K. L. Wildes
Michigan Col. of Mining & Tech., Houghton	5	G. W. Swenson
Michigan State Col., East Lansing	5	M. M. Cory
Michigan, Univ. of, Ann Arbor	5	J. S. Gault
Milwaukee School of Engg., Milwaukee, Wis.	5	E. L. Wiedner
Minnesota, Univ. of, Minneapolis	5	J. H. Kuhlmann
Mississippi State Col., State College	4	L. L. Patterson
Missouri School of Mines & Met., Rolla	7	F. H. Frame
Missouri, Univ. of, Columbia	7	M. P. Weinbach
Montana State Col., Bozeman	9	E. W. Schilling
Nebraska, Univ. of, Lincoln	6	O. E. Edison
Nevada, Univ. of, Reno	8	S. G. Palmer
Newark Col. of Engineering, Newark, N. J.	3	S. Fishman
New Hampshire, Univ. of, Durham	1	W. B. Nulsen
New Mexico State Col., State College	7	M. A. Thomas
New Mexico, Univ. of, Albuquerque	7	R. W. Tapy
New York, Col. of the City of, New York	3	Harry Baum
New York Univ., New York	3	P. C. Cromwell
North Carolina State Col., Raleigh	4	L. M. Keever
North Dakota State Col., Fargo	5	H. S. Rush
North Dakota, Univ. of, Grand Forks	5	C. W. Rook
Northeastern Univ., Boston, Mass.	1	R. G. Porter
Northwestern Univ., Evanston, Ill.	5	R. W. Jones
Norwich Univ., Northfield, Vt.	1	F. A. Spencer
Notre Dame, Univ. of, Notre Dame, Ind.	5	J. A. Northcott
Ohio Northern Univ., Ada	2	G. W. Klein
Ohio State Univ., Columbus	2	S. O. Evans
Ohio Univ., Athens	2	W. M. Young
Oklahoma A. & M. College, Stillwater	7	A. Naeter
Oklahoma, Univ. of, Norman	7	R. A. Church
Oregon State Col., Corvallis	9	A. L. Albert
Pennsylvania State Col., State College	2	P. X. Rice
Pennsylvania, Univ. of, Philadelphia	2	S. R. Warren, Jr.
Pittsburgh, Univ. of, Pittsburgh, Pa.	2	R. C. Gorham
Pratt Institute, Brooklyn, N. Y.	3	D. H. Wright
Princeton Univ., Princeton, N. J.	2	W. C. Johnson
Puerto Rico, Univ. of, Mayaguez, P. R.	3	M. Wiewall, Jr.
Purdue Univ., Lafayette, Ind.	5	R. B. Marshall
Rensselaer Polytechnic Inst., Troy, N. Y.	1	E. D. Broadwell
Rhode Island State Col., Kingston	1	W. J. Mowbray
Rice Inst., Houston, Tex.	7	C. R. Wischmeyer
Rose Polytechnic Inst., Terre Haute, Ind.	5	C. C. Knipmeyer
Rutgers Univ., New Brunswick, N. J.	3	J. L. Potter
Santa Clara, Univ. of, Santa Clara, Calif.	8	W. J. Warren
South Carolina, Univ. of, Columbia	4	W. M. Bauer
South Dakota State College, Brookings	5	W. H. Gamble
South Dakota State School of Mines, Rapid City	6	E. E. Clark
Southern California, Univ. of, Los Angeles, Calif.	8	P. S. Biegler
Southern Methodist Univ., Dallas, Tex.	7	E. H. Flath
Stanford Univ., Stanford University, Calif.	8	H. H. Skilling
Stevens Inst. of Technology, Hoboken, N. J.	3	W. L. Sullivan
Swarthmore Col., Swarthmore, Pa.	2	
Syracuse Univ., Syracuse, N. Y.	1	C. W. Henderson
Tennessee, Univ. of, Knoxville	4	W. O. Leffell
Texas A. & M. Col., College Station	7	M. C. Hughes
Texas Technological Col., Lubbock	7	C. V. Bullen
Texas, Univ. of, Austin	7	A. W. Straiton
Tufts College, Tufts College, Mass.	1	A. H. Howell
Tulane Univ., New Orleans 15, La.	4	M. G. Zervigon
Union Col., Schenectady 5, N. Y.	1	H. W. Bibber
Utah, Univ. of, Salt Lake City	9	O. C. Haycock
Vanderbilt Univ., Nashville, Tenn.	4	S. R. Schealer
Vermont, Univ. of, Burlington	1	E. R. McKee
Villanova Col., Villanova, Pa.	2	H. S. Bueche
Virginia Military Inst., Lexington	4	J. S. Jamison
Virginia Polytechnic Inst., Blacksburg	4	Claudius Lee
Virginia Univ. of, University	4	J. S. Miller
Washington, State College of, Pullman	9	H. F. Lickey
Washington, Univ. of, Seattle	9	R. E. Lindblom
Washington Univ., St. Louis, Mo.	7	D. A. Fischer
West Virginia Univ., Morgantown	2	A. H. Forman
Wisconsin, Univ. of, Madison	5	G. F. Tracy
Worcester Polytechnic Inst., Worcester, Mass.	1	V. Siegfried
Wyoming, Univ. of, Laramie	6	R. O. Trueblood
Yale Univ., New Haven, Conn.	1	A. G. Conrad
Total Branches	125	

Local Sections of the Institute

Name	District	When Organized	Membership Aug. 1, 1944	Chairman	Secretary	Secretary's Address
Akron	2	Aug. 12, '20	104	A. G. Seifried	P. S. Bechtol	1359 Ottawa Ave., Akron 5, Ohio
Alabama	4	May 22, '29	44	F. G. Hamner	T. E. Curtis	Southern States Equipment Corp., 28 S. 20th St., Birmingham 3, Ala.
Arizona	8	Mar. 22, '41	50	C. R. Smith	E. A. Gissel	Central Arizona Light & Power Co., Phoenix, Ariz.
Boston	1	Feb. 13, '03	604	A. L. O'Banion	R. E. Muehlig	Westinghouse Elec. & Mfg. Co., 235 Old Colony Ave., Boston, Mass.
Central Indiana	5	Jan. 12, '12	148	C. E. Parks		
Chicago	5	1893	869	R. C. Ericson	J. F. Calvert	Northwestern Technological Institute, Evanston, Ill.
Cincinnati	2	June 30, '20	149	A. J. Allen	G. W. Coulehan	607 Chamber of Commerce Bldg., Cincinnati 2, Ohio
Cleveland	2	Sept. 27, '07	390	W. R. Hough	J. D. Leitch	The Electric Controller & Mfg. Co., 2700 E. 79th St., Cleveland, Ohio
Columbus	2	Mar. 17, '22	94	R. W. Miner	E. M. Boone	Dept. of Elec. Engg., Ohio State University, Columbus, Ohio
Connecticut	1	Apr. 16, '21	363	Carl F. Scott	C. D. Hewitt	P.O. Box 1562, New Haven 6, Conn.
Dayton	2	June 9, '43	173	J. W. Gehrke	F. S. Himebrook	Master Electric Co., Dayton, Ohio
Denver	6	May 18, '15	192	Hubert Sharp	L. R. Patterson	Public Service Co. of Colorado, Denver, Colo.
East Tennessee	4	Sept. 2, '36	206	J. D. Harper	F. A. Hoeke	General Electric Co., 602 S. Gay St., Knoxville, Tenn.
Erie	2	Jan. 11, '18	74	J. Hause	W. C. Brown	General Electric Co., Erie, Pa.
Florida	4	Jan. 28, '31	134	C. F. Titus	P. J. Carlin	Florida Power & Light Co., Miami, Fla.
Fort Wayne	5	Aug. 14, '08	107	W. W. Brooks	S. A. Zimmermann	2600 Hoagland Ave., Fort Wayne, Ind.
Georgia	4	Jan. 14, '04	115	T. J. Woth	R. O. Loomis	Georgia Power Co., Atlanta 1, Ga.
Houston	7	Aug. 7, '28	180	Hezzie Clark	R. S. Kersh	612 Petroleum Bldg., Houston 2, Texas
Iowa	5	June 29, '29	78	E. B. Fowler	H. R. Reed	State University of Iowa, Iowa City, Iowa
Ithaca	1	Oct. 15, '02	65	E. M. Strong	H. G. Smith	Cornell University, School of Elec. Engg., Ithaca, N. Y.
Kansas City	7	Apr. 14, '16	146	M. E. Bretschneider	P. C. Cross	General Electric Co., 106 W. 14th St., Kansas City 6, Mo.
Lehigh Valley	2	Apr. 16, '21	179	H. E. Pearson	J. A. G. Oewel	Penn. Pwr. & Lt. Co., 901 Hamilton St., Allentown, Pa.
Los Angeles	8	May 19, '08	635	P. L. Johnson	E. W. Morris	Westinghouse Elec. & Mfg. Co., 420 So. San Pedro St., Los Angeles 13, Calif.
Louisville	4	Oct. 15, '26	75	M. S. Winstandley	S. H. Gates	So. Bell Tel. & Tel. Co., 521 W. Chestnut St., Louisville 2, Ky.
Lynn	1	Aug. 22, '11	211	M. S. Wilson	R. G. Connors	788 Broad St., Lynn, Mass.
Madison	5	Jan. 8, '09	75	F. D. Mackie	G. F. Tracy	Elec. Lab., University of Wisconsin, Madison 5, Wis.
Mansfield	2	Mar. 6, '39	65	J. M. Robinson	H. G. Duhamel	North Electric Mfg. Co., Galion, Ohio
Maryland	2	Dec. 16, '04	381	B. Van Ness, Jr.	H. H. Angel	Bethlehem Steel Co., Sparrows Point, Md.
Memphis	4	May 22, '30	72	T. H. Allen	J. A. Crisman	Westinghouse Elec. & Mfg. Co., 825 Exchange Bldg., Memphis 1, Tenn.
Mexico	3	June 29, '22	83	F. A. Nava	F. Aubert	Apartado Postal 1399, Mexico, D.F. Mexico
Michigan	5	Jan. 13, '11	404	M. M. Cory	L. W. Clark	Detroit Edison Co., 2000—2nd Ave., Detroit 26, Mich.
Milwaukee	5	Feb. 11, '10	371	T. B. Jochem	J. W. Pomazal	Louis Allis Co., 427 E. Stewart St., Milwaukee 4, Wis.
Minnesota	5	Apr. 7, '02	124	C. W. Lethert	F. W. Hotchkiss	Electric Machine Mfg. Co., Minneapolis, Minn.
Montana	9	June 24, '31	36	I. J. Buergey	W. R. Neumann	Montana Power Company, Great Falls, Mont.
Montreal	10	Apr. 16, '43	208	F. L. Lawton	J. R. Auld	Canadian Industries Ltd., Engg. Dept., Montreal, P.Q., Canada
Muscle Shoals	4	Feb. 18, '38	22	Leo King	Arthur Vaughn	702 Commons, Tuscumbia, Ala.
Nebraska	6	Jan. 21, '25	51	Donald Thomas	I. M. Ellestad	Northwestern Bell Telephone Co., Omaha, Nebr.
New Mexico–West Texas	7	Mar. 7, '40	54	R. C. Dickson	J. F. Armstrong	3219 Altura Blvd., El Paso, Tex.
New Orleans	4	Dec. 8, '33	151	B. H. Bell	L. J. Olivier	Louisiana Pwr. & Lt. Co., New Orleans 14, La.
New York	3	Dec. 10, '19	3,814	M. D. Hooven	W. S. Hill	General Electric Co., 570 Lexington Ave., New York 22, N. Y.
Niagara Frontier	1	Feb. 10, '25	185	W. K. Parks	W. J. Freudenberger	Buffalo Niagara Elec. Corp., 300 Electric Bldg., Buffalo 3, N. Y.
North Carolina	4	Mar. 21, '29	119	H. B. Robinson	L. M. Keever	North Carolina State College, Raleigh, N. C.
North Texas	7	May 18, '28	177	E. H. Flath	R. W. Roesler	1007 Insurance Bldg., Dallas, Tex.
Oklahoma City	7	Feb. 16, '22	100	C. L. Farrar	C. L. Jobe	Oklahoma Gas & Electric Co., Oklahoma City 2, Okla.
Philadelphia	2	Feb. 18, '03	892	A. C. Muir	M. L. Lehman	American Tel. & Tel. Co., 530 Bourse Bldg., Philadelphia 6, Pa.
Pittsburgh	2	Oct. 13, '02	663	R. C. Gorham	C. M. Skooglund	West Penn Power Co., 14 Wood St., Pittsburgh 30, Pa.
Pittsfield	1	Mar. 25, '04	196	J. L. Cantwell	T. E. Rodhouse	General Electric Co., 100 Woodlawn Ave., Pittsfield, Mass.
Portland	9	May 18, '09	189	W. E. Enns	O. A. Demuth	Box 3537, Portland 12, Ore.
Providence	1	Mar. 12, '20	101	R. E. Secord	G. E. Andrews	The Narragansett Elec. Co., 49 Westminster St., Providence, R. I.
Rochester	1	Oct. 9, '14	124	O. L. Angevine, Jr.	E. B. Kempster	General Motors Corp., Rochester 3, N. Y.
St. Louis	7	Jan. 14, '03	320	C. M. Lovell	Ray Robson	Union Electric Co. of Missouri, Webster Groves, Mo.
San Diego	8	Jan. 18, '39	74	W. J. Kenline	C. F. McCabe	Consolidated Aircraft Corp., Lindbergh Field, San Diego, Calif.
San Francisco	8	Dec. 23, '04	682	G. C. Tenney	A. Tilles	Dept. of Elec. Engg., Univ. of California, Berkeley, Calif.
Schenectady	1	Jan. 26, '03	619	L. A. Umansky	L. T. Rader	General Elecric Co., Industrial Control Engg. Dept., Schenectady, N. Y.
Seattle	9	Jan. 19, '04	274	C. H. Cutter	H. R. Brown	2136—47th Ave., S.W., Seattle 6, Wash.
Sharon	2	Dec. 11, '25	135	F. D. Fielder	A. D. Forbes	Westinghouse Elec. & Mfg. Co., Sharon, Pa.
South Bend	5	Feb. 26, '41	60	C. M. Dunn	C. D. Highleyman	Indiana & Michigan Elec. Co., So. Bend, Ind.
South Carolina	4	Mar. 2, '40	47	W. H. Kendrick	F. T. Tingley	Clemson College, Clemson, S. C.
South Texas	7	May 23, '30	48	I. A. Uhr	O. T. Lodal	1411 Smith Young Tower, San Antonio, Tex.
Spokane	9	Feb. 14, '13	103	R. G. Kelly	G. H. Sargeant	Aluminum Co. of America, Box 6116, Hillyard Sta., Spokane 14, Wash.
Springfield	1	June 29, '22	55	L. P. Kongsted	W. S. Scheering	Western Massachusetts Cos., 73 State St., Springfield 2, Mass.
Syracuse	1	Aug. 12, '20	126	J. W. Dice	C. E. von Sothen	General Electric Co., 113 S. Salina St., Syracuse, N. Y.
Toledo	2	June 3, '07	87	R. L. Manor	W. M. Campbell	2145 Central Grove Ave., Toledo, Ohio
Toronto	10	Sept. 30, '03	381	A. W. Murdock	J. F. Moore	Dunlop Wire & Rubber Goods Ltd., 870 Queen St. E., Toronto, Canada
Tulsa	7	Oct. 1, '37	73	H. A. Norberg	E. F. Patterson	General Electric Co., 405 Mid-Continent Bldg., Tulsa, Okla.
Urbana	5	Nov. 25, '02	87	E. A. Reid	P. F. Schwartzlose	212 Elec. Engg. Lab., University of Illinois, Urbana, Ill.
Utah	9	Mar. 9, '17	79	E. Bachman	J. A. McDonald	General Elec. Co., P.O. Box 779, Salt Lake City 9, Utah
Vancouver	10	Aug. 22, '11	101	L. B. Stacey	G. K. Haspel	1992 West 41st Ave., Vancouver, B. C., Canada
Virginia	4	May 19, '22	147	C. E. Creecy	A. F. Forbes	Newport News ShipBuilding & Drydock Co., Newport News, Va.
Washington	2	Apr. 9, '03	707	W. F. Dietz	H. M. Bollinger	Chesapeake & Potomac Tel. Co., 1111 N. Capitol St., Washington 2, D. C.
West Virginia	2	Apr. 9, '40	39	L. W. Roush	E. B. Ellerbe	Box 911, Charleston 23, W. Va.
Wichita	7	Sept. 16, '37	74	E. H. Stephens	H. E. Hartman	Kansas Gas & Elec. Co., 201 N. Market St., Wichita 1, Kansas
Worcester	1	Feb. 18, '20	65	V. F. P. Sepavich	R. M. Peirce	American Steel & Wire Co., Electrical Cable Works, Worcester, Mass.
Total Sections	73		18,415			

Local Subsections

Beaumont (Houston Section)	L. H. Matthes	G. W. Morgan	P.O. Box 2951, Beaumont, Tex.
Hamilton (Toronto Section)	H. W. Blackett	K. R. Knights	Canadian Westinghouse Co. Ltd., Hamilton, Ont., Canada
Illinois Valley (Urbana Section)	G. B. Smedley	F. A. Ericson	Central Illinois Light Co., Peoria, Ill.
Niagara Falls (Niagara Frontier Section)	Edw. Bond, Jr.	F. A. Anderson	1021—90th St., Niagara Falls, N. Y.
Ottawa (Montreal Section)	B. G. Ballard	J. H. Simpson	National Research Council, Ottawa, Ont., Canada
Rock River Valley (Madison Section)	C. V. Bullen	B. T. Anderson	625 Rome Ave., Rockford, Ill.
Wilmington (Philadelphia Section)	K. Pinder	Henry Evans	Delaware Pwr. & Lt. Co., 600 Market St., Wilmington, Del.
Zanesville (Columbus Section)	J. H. Ludden	J. G. Tankovich	Line Material Co., Zanesville, Ohio

OF CURRENT INTEREST

Adapter Plug Provides Mobility for Field Switchboards

A new light compact telephone switching unit developed by the Signal Corps, Army Service Forces, is supplanting for emergency field service the bulky switchboards hitherto used. This unit, the Adapter Plug *U–4/GT*, can be used for terminating a local battery telephone line, and several plugs, used with a field telephone for the operator's set, will provide a workable switchboard substitute which may be set up rapidly.

Weighing only one ounce, the plug can be transported to many spots inaccessible to a battery switchboard. It also is moisture-proof which makes it invaluable for jungle or mountain operations, for beach landing in rain-drenched areas, and for air-borne operations behind the enemy lines. The transparent plastic body of the plug contains fasteners for line connections, a neon lamp that responds to ringing signals, and two combination jacks and plugs for tandem connections between adapter plugs. The resistance and neon lamp are inside the plastic body which makes them virtually impervious to moisture and fungus attacks. A luminescent identification plate on which the operator may enscribe the line number is embedded in the plastic.

The plug builds up a flexible switchboard upon which the operator can make not only individual connections but also conference connections by calling individually the parties desired and connecting the adapter plugs in tandem.

The *U–4/GT* was developed in response to an elementary need, realized especially in the Pacific war theater, of substituting a visual signal for the bell signal. The latter could be heard from considerable distances by enemy snipers. Extension of the use of the plugs to the building of substitute emergency switchboards was a by-product. The visual signal functions when the operator attaches the field-wire pair entering his outpost to an adapter plug and connects his telephone by a short length of field wire to another adapter plug. Incoming calls flash the lamp in the first plug.

Packaged Carrier Facilitates Work of Signal Corps

A "packaged carrier," which enables non-technical men with only a rudimentary knowledge of communications work to set up field units and to operate them with complete success, is a partial explanation of how the Plant Engineering Agency of the Signal Corps' Army Communications Service, an organization of only 1,400 officers and enlisted men, has been able to erect over 400 large-sized installations for the Army since October 1943.

The packaged carrier is a prefabricated kit of communications equipment, so simple as to be almost foolproof, accompanied by clear and specific instructions. By using the kit, a number of messages can be sent simultaneously, both by voice and telegraph, upon two open telephone wires. The messages are unscrambled at the receiving end.

The Plant Engineering Agency functions on a world-wide scale and is responsible for installing and maintaining all fixed communications of the Army, among which meteorological stations and air base radio stations are especially numerous. The Agency crews often work under enemy fire as well as under natural disadvantages in setting up field radio stations. For example, when coral atolls selected for invasion have been too small to hold their equipment, it sometimes has been necessary to land the receiving and transmitting equipment on adjacent islands separated by vulnerable open channels. Through the work of the Agency, field headquarters in every theater of war can communicate instantly with the commanding general and with the War Department in Washington, D. C. Agency headquarters are in Philadelphia, Pa., under the command of Colonel Will V. Parker.

Radio Outfitting of B-29 Bomber Is Signal Corps Achievement

When the Army Air Forces *B*-29 Superfortress takes off on a bombing mission, it carries 2,000 pounds of Signal Corps aircraft radio equipment. This load is nearly double the amount normally carried by the Flying Fortress, the Liberator, and other heavy bombers.

The radio sets installed range from one-half pound to 550 pounds in weight and provide for communication between aircraft in flight, between the bombers and their distant bases, and between crew members within the airplane. Navigational devices allow the pilot to fly a direct or diverse course, to locate bases precisely on his return, and to execute safe landings. Devices to guide rescuers to a forced landing at sea also are included. No new equipment was designed for the Superfortress, but selection from the types available was made on the basis of performance on long-range flights.

According to Colonel Hobart R. Yeager, commanding officer of the Signal Corps Aircraft Signal Agency, the radio complement for the superbomber was the largest single installation job ever undertaken by the Signal Corps laboratory at Wright Field. Technical problems encountered by the laboratory were numerous, Colonel Yeager said, because of the great number of different types of radio equipment which had to be made to operate without neutralizing each other. The altitude range of the bomber and the construction design also raised problems.

Officers and civilian engineers of Aircraft Radio Laboratory have been engaged on the *B*-29 project since it was first launched by the AAF. Early in 1940 the laboratory prepared specifications and other data relative to radio requirements which were incorporated in the first experimental model. Late in 1943 engineering personnel of the laboratory completed the first installation of radio equipment in a production model.

Army and Navy Co-operation Speeds up Specification Routines

Reports indicate that over 1,500 qualification approvals have been co-ordinated between the Signal Corps and the Bureau of Ships as a result of the program, inaugurated about 18 months ago, of standardization of Army and Navy specifications for communication equipment.

Army–Navy co-ordination of standards has been facilitated by two agencies: the Signal Corps Standards Agency, organized under a

The Superfortresses move two abreast through three 300-foot-wide assembly bays at the Boeing–Renton plant constructed by the Austin Company, engineers and builders. There is more than 1,000,000 square feet of these 300-foot clear-span areas in the three Boeing plants now producing the United States's heaviest bomber

joint agreement between Lieutenant General Brehon Somervell and Vice-Admiral Samuel Robinson, and the Army–Navy Electronics Standard Agency. Both are in Red Bank, N. J.

Under the new time-saving program, the qualification tests for each type of equipment are made by only one agency and the data forwarded to other interested agencies as a basis for approvals. Plastics, for example, are tested by the Bureau of Ships and dry batteries by the Signal Corps. Specifications on the materials tested are being compiled as joint Army–Navy Standards and will be used by all of the services of the Army and all the bureaus of the Navy. Joint inspection of equipment and co-ordination of waivers similarly are replacing former duplication. When, as happened with vacuum tubes and radio-frequency cables, the routine procedures of the Signal Corps Standards Agency and ANESA have been found insufficient, special groups or subcommittees are set up.

INDUSTRY • • • • •

NAM Advises Training Foremen to Readjust Veterans to Industry

The special training of foremen for their part in the rehabilitation of veterans into industry recently was called the foremost objective of management's responsibility in rehabilitating the veterans in a report of the committee on supervisory relations of the National Association of Manufacturers.

Preparatory guidance and information which will enable the foreman to develop the right attitude toward the problem and a better understanding of how to deal soundly with veterans can be given through intelligent foreman conferences, special bulletins, and other mediums, according to the committee. Specifically, the committee recommended that management provide supervisory personnel with some training and information on these points:

1. The employer's legal obligations embodied in section 8 of the Selective Service Law, particularly the provisions related to the veteran's rights to his former job.

2. The effect of section 8 on the seniority practices of industry generally and the particular company's stated and contractual seniority practices.

3. The GI Bill of Rights, its provisions, and the various benefits it grants veterans.

4. The company's veteran employment program, as it variously concerns veterans who were former employees, veterans who were not prewar employees but have had experience in similar work, and veterans who are being employed for the first time and need indoctrination into industry.

5. Human and technical problems involving the foreman's friendly understanding of the fact that the veteran is eager to succeed on the job and the fact that it is the foreman's duty to see that the veteran is given the full benefit of assistance from both the personnel and medical departments in order to fit smoothly into his working life.

6. The physically handicapped need proper placement and, when fitted into the right job and properly trained, they are wholly productive. Veterans still undergoing medical treatment need to have their time arranged so that they may continue any treatments necessary to bring them back to normal health.

Committee members from the electrical industry include: T. O. Armstrong, manager industrial relations, Westinghouse Electric and Manufacturing Company, Springfield, Mass.; R. C. Cosgrove, vice-president and general manager, the Crosley Corporation, Cincinnati, Ohio; H. H. Kerr (M '26) general superintendent, the Toledo Edison Company, Toledo, Ohio; and H. J. Robertson, Jr., president, the Fibre Conduit Company, Orangeburg, N. Y.

Industrial Protection From X Rays Studied by ASA

Initiation of a new project to develop and standardize means of protection from X-ray burns in industry has been announced by the American Standards Association. The X ray recently has become a prominent method of inspection in meeting the rigid requirements for metal castings, welding, and the like in war industries. Its use has increased about 2,000 per cent in the past two years, and few, if any, city or state safety codes insure protection from X-ray radiation for operators or others working near X-ray machines. The project which was undertaken at the request of the Department of Labor will be carried on under the American War Standard procedure of the association.

The portable type of machine which can direct rays at any angle presents a particularly difficult safety problem, according to the ASA announcement. With the greater number of workers necessarily new and inexperienced and often without benefit of adequate instruction, the use of this equipment may cause grave injury. Unfortunately, some of the most serious effects of overexposure to X rays may not be detected for years. Symptoms of the more usual maladies, skin cancer, anemia, sterilization, and cataract are slow in developing.

New Magazine for Latin America Issued. A new bimonthly technical magazine, *El Ingeniero Westinghouse*, printed in Spanish and made up of articles from recent issues of *Westinghouse Engineer*, plus additional engineering information for readers in Central and South America, makes its initial appearance this month, according to announcement from John W. White, president and general manager of the Westinghouse Electric International Company. The new publication will be dedicated to increased co-operation among the Americas, and is designed to keep its readers informed on vital developments in Latin America.

RMA Announces Formation of Two New Committees

Formation of two new committees, the Radio Technical Planning Board television reporting committee and the school sound systems committee, is announced by Radio Manufacturers' Association.

The RTPB television reporting committee under the chairmanship of Ray H. Manson (M '18) of Rochester, N. Y., will review the forthcoming report of RTPB television panel 6 and prepare official RMA views on the development and promotion of television. The School Sound systems committee, headed by Chairman L. A. King of St. Charles, Ill., will develop specifications and promote public-address equipment in schools and similar institutions and will co-operate with the board of education and committees of the Federal Communications Commission and other industry groups on school apparatus.

Three RMA committees have been discontinued: the postwar planning committee, the legislative committee, and the replacement parts committee. Functions of the disbanded committees have been taken over by other still existing committees of RMA.

EDUCATION • • •

Acoustical Research Instituted at Rutgers University

Organization of the division of acoustical research in the college of engineering for the purpose of investigating air-borne sounds, has been announced by Rutgers University, New Brunswick, N. J. The work of the division will be carried on under contract with the Office of Scientific Research and Development and will be directed by Carl F. Eyring, professor of physics, Brigham Young University, Salt Lake City, Utah. Other members of the staff are: Arthur A. Allen, professor of ornithology, Cornell University, Ithaca, N. Y.; Wayne B. Hales, professor of physics, Brigham Young University; James L. Potter (A '41) professor of electrical engineering, Rutgers University; Peter P. Kellogg, assistant professor of ornithology, Cornell University; Obed C. Haycock (M '39) associate professor of electrical engineering, University of Utah, Salt Lake City; William L. Nastuk, assistant in physiology, Rutgers University; Anthony J. Del Mastro, instructor in civil engineering, Rutgers University.

Colleges Prepare for Admission Problems of Veterans

As the end of the war approaches the problem of establishing equitable and educationally sound policies for granting college credit to the returning veterans who have had specialzied training or who have studied either independently or under the direction of the Armed Forces Institute while in military service confronts the colleges and universities with greater immediacy.

To aid institutions seeking advice, the committee on accrediting procedures of the American Council on Education has made a thorough study of the problem and reviewed the findings and suggestions of representative college-admission officers, registrars, and deans who have surveyed the operations of the Armed Forces Institute. By its recommendations the committee hopes to counteract any trend toward lowering educational standards because of pressure from interested groups including legislative bodies or from the competition for students existing among some colleges.

Pointing out that the commanding officers in charge of the Army's schools are not authorized to recommend to educational institutions the amount of credit that should

New Switchboard for Western Steel Mill

Westinghouse Photo

This supervisory control board in the switch house at the Geneva Steel Company, a subsidiary of the United States Steel Corporation, controls and supervises more than 500 points of switching and apparatus control in all distribution substations and motor rooms throughout the entire plant

be allowed for the various training programs under their jurisdiction, the committee made the following recommendations for evaluating military educational experience:

1. For technical and vocational training gained in the services, credit should be given only if the fields correspond to subjects for which the institutions regularly grant credit.

2. If a member of the Armed Forces believes that he has mastered the content of a course accredited by an institution, he should have the opportunity to demonstrate his eligibility for such credit in an examination compiled either by the institution or the Armed Forces Institute.

3. Credit for specialized training courses carried on by regular university staffs for the Armed Forces should be allowed in accordance with an institution's regular policies. A transcript containing a detailed description of the courses should be issued for transfer to another institution.

4. For Army Specialized Training Program and Navy V-12 courses, the transcript should be accompanied by a statement of the courses' equivalent in terms of those regularly offered to civilians.

5. A member of the Armed Forces who demonstrates his competence in an approved examination should be considered for admission to college.

6. Upon satisfactory completion of correspondence courses given by a recognized college or university in co-operation with the Armed Forces Institute, credit should be allowed a student on the basis of the policies adopted by the individual institution.

7. Credit should be officially recorded by the college only for students who have been or are under instruction by that institution. This is not to be construed, however, as limiting the college in advising students regarding their probable classification in the institution.

Also pertinent to the colleges' problem is the preparation by the Armed Forces of a standard form reporting military experience which has a bearing on school and college credit. This form which includes data on training experiences, off-duty education, and individual educational activities will be available to all branches of the Armed Forces.

Upon the committee's recommendation the accrediting and educational associations have contributed substantial sums for the financial support of a staff whose present activities are:

1. Preparation of a "Guide to the Evaluation of Educational Experiences in the Armed Services" for distribution to schools and colleges. This handbook describes the formal training programs of the armed services and recommends for each program the base upon which credit should be awarded.

2. Assistance to higher education institutions and secondary schools on policies for interpreting examination reports and records of military service provided by the Armed Forces Institute or by the several branches of the Armed Forces.

3. Collection of information from educational institutions regarding their policies with reference to credit for educational experience gained in the armed services.

4. Assistance to higher institutions and secondary schools at their request in developing procedures to put into operation the general policies recommended by the committee on accrediting procedures of the American Council on Education.

Inquiries for further information concerning these services and orders for the guide which is two dollars per copy, should be addressed to G. P. Tuttle, 363 Administration Building, Urbana, Ill.

OTHER SOCIETIES •

American Co-ordinating Committee on Corrosion Elects Officers

Frank L. LaQue of the development and research division of International Nickel Company was elected chairman of the American Co-ordinating Committee on Corrosion at its sixth annual meeting held recently. George H. Young of the Mellon Institute of Industrial Research was named vice-chairman, and George W. Seagren, also of the Mellon Institute was elected secretary-treasurer.

The Co-ordinating Committee, organized in 1938, serves as a clearing house and co-ordinating agency for information on American experience and American work in progress in the field of corrosion and corrosion prevention, and acts as an agency for the exchange of corrosion information and experience with similar foreign agencies such as the corrosion committee of the British Iron and Steel Institute. The Committee is composed of official delegates from the following societies: American Foundrymen's Association, American Gas Association, American Institute of Chemical Engineers, AIEE, American Society of Mechanical Engineers, American Society for Metals, American Society of Refrigerating Engineers, American Society for Testing Materials, American Water Works Association, Armour Research Foundation, Battelle Memorial Institute, The Electrochemical Society, Mellon Institute of Industrial Research, National Bureau of Standards, National District Heating Association, National Research Council, Society of Automotive Engineers.

Six subcommittees have been active in the past several years, co-ordinating studies on underwater paints, co-operating with the British Admiralty Marine Corrosion Committee, examining and approving applications for grants-in-aid from the research fund offered by the American Society for Metals for the support of fundamental research on corrosion, standardizing corrosion test materials and terms and symbols, and advising the Navy's Bureau of Ships on special problems on request.

ASTM Officers Announced

American Society for Testing Materials announces its new officers, elected at its annual meeting held recently. They are:

President: P. H. Bates, chief, clay and silicate products division, National Bureau of Standards, Washington, D. C.

Vice-president: Arthur W. Carpenter, manager, testing laboratories, The B. F. Goodrich Company, Akron, Ohio.

Members of the executive committee: W. C. Hanna, chief chemist and chemical engineer, California Portland Cement Company, Colton, Calif.; L. B. Jones, engineer of tests, test department, The Pennsylvania Railroad Company, Altoona, Pa.; J. T. MacKenzie, chief metallurgist, American Cast Iron Pipe Company, Birmingham, Ala.; J. G. Morrow, chief metallurgist, The Steel Company of Canada, Ltd., Hamilton, Canada; Sam Tour, president, Sam Tour and Company, Inc., New York, N. Y.

Elected to honorary membership were the following authorities in the field of engineering materials:

Rudolph Philip Miller, consulting engineer, New York City, dean of building-code experts, and authority on construction, fire tests of materials; Milton Earl McDonnell, former chief chemist, Pennsylvania Railroad Company; and Hermann Von Schrenk, consulting timber engineer for many of the country's railroad systems and authority on wood and timber—its procurement and utilization, prevention of disease, and decay.

Standard for Terminal Markings Revised by ASA and NEMA

The fourth edition of the "American Standard for Terminal Markings for Electrical Apparatus C6.1–1944" has been completed under the sponsorship of the National Electrical Manufacturers Association and approved by the American Standards Association.

The Standard covers the following apparatus: a-c and d-c generators, single-phase and other capacitor motors, power and distribution transformers, feeder voltage regulators, electric water heaters, attachment plugs and receptacles, industrial control, instrument transformers, and current-limiting reactors.

The sections dealing with markings for instrument transformers and reactors have

Future Meetings of Other Societies

American Association for the Advancement of Science. Annual meeting, September 11–16, 1944, Cleveland, Ohio.

American Chemical Society. 108th annual meeting, September 11–15, 1944, New York, N. Y.

American Society of Mechanical Engineers. Fall meeting, October 2–5, 1944, Cincinnati, Ohio; annual meeting, November 27–December 1, 1944, New York, N. Y.

American Welding Society. Annual meeting, October 16–19, 1944, Cleveland, Ohio.

Association of Iron and Steel Engineers. Annual meeting, September 25–27, 1944, Pittsburgh, Pa.

Edison Electric Institute. Accident prevention committee, September 12–13, 1944, New York, N. Y.; prime movers committee, October 2–3, 1944, Pittsburgh, Pa.; electrical equipment committee, October 5–6, 1944, Pittsburgh; transmission and distribution committee, October 9–10, 1944, Buffalo, N. Y.

Electrochemical Society. Fall meeting, October 12–14, 1944, Buffalo, N. Y.

Electronic Parts and Equipment Industry Conference. October 19–21, 1944, Chicago, Ill.

Engineers' Council for Professional Development. Annual meeting, October 20, 1944, New York, N. Y.

Illuminating Engineering Society. Annual convention, September 14–16, 1944, Chicago, Ill.

Institute of the Aeronautical Sciences. Air transport meeting, September 1944, Washington, D. C.; fall meeting, November 1944, Dayton, Ohio.

National Electrical Contractors Association. Annual meeting, October 1–5, 1944, French Lick, Ind.

National Electrical Manufacturers Association. October 23–27, 1944, New York, N. Y.

National Electronics Conference. October 5–7, 1944, Chicago, Ill.

National Industrial Chemical Conference and Third National Chemical Exposition. November 15–19, 1944, Chicago, Ill.

National Safety Congress of the National Safety Council. October 3–5, 1944, Chicago, Ill.

Society of Motion Picture Engineers. 56th semiannual fall conference, October 16–18, 1944, New York, N. Y.

been enlarged and the material co-ordinated with similar provisions in the American Standard for Transformers C57. An entirely new section on electric water heaters has been added. For the first time color is employed as a means of identification in the wiring of electric water heaters and associated devices. The "American Standard Terminal Markings for Electrical Apparatus C6.1–1944" may be obtained from the American Standards Association, 29 West 39th Street at $1 per copy.

Canadian Electrical Code in Process of Revision

Consideration now is being given to a general revision of the Canadian Electrical Code, part I, preparatory to publication of a fifth edition. Subcommittees organized to review the various sections of the code now are engaged in the work of revision.

Any and all proposals for revision will be welcome and should be submitted without delay in order that fullest consideration may be given them well in advance of the closing date for receipt of proposals. All such proposals should, if possible, be in the form of the actual text desired for incorporation into the fifth edition.

The closing date for receipt of proposals for revision is October 1, 1944. Requests for revision received after that date may be held for the next general revision. This notice is directed particularly to electrical interests in Canada and to electrical manufacturers in Great Britain and the United States who export electrical equipment and appliances to Canada. Proposals should be addressed to: The Secretary, Canadian Standards Association, National Research Building, Ottawa, Ont., Canada.

British Standard on Telecommunication. The "Glossary of Terms Used in Telecommunication," published in Great Britain in 1943 by the British Standards Institution and received recently by the American Standards Association library covers essentially the same subject matter as the sections on electrocommunication and electronics of the "American Standard Definitions of Electrical Terms, *C42–1941*." The British Standard, however, includes more terms than the American Standard. The terms "klystron" and "rhumbatron" are defined in the British glossary for the first time in any official standards publication.

Standard for Dial Indicators Issued. A new Commercial Standard for Dial Indicators, *CS(E)* 119–45, has been accepted by the National Bureau of Standards and will become effective for new production January 1, 1945. The purpose of the commercial standard for which acceptances have been received from manufacturers, distributors, and users, is to provide minimum essential requirements for precision dial indicators as a basis for a better understanding between sellers and buyers, for fair competition, and for purposes of identification of precision dial indicators.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

The Engineering Degree

To the Editor:

Mr. Gould's comments on the various types of engineering degree (*EE, June '44, p. 278–9*) are worthy of action by the various scientific societies.

It is difficult to change existing practice but the right thing to do would be to revamp the requirements and authorization for granting a degree. You could have one degree used for honorary issuance, then limit the highest degree granted for college work to a masters degree, then have all higher degrees first approved by a joint scientific societies committee.

The promiscuous and professionally uncontrolled requirements for granting a degree is cheapening the scientific profession. All the scientific societies should set up jointly a schedule of performance requirements that permits a tangible scoring of measurable accomplishments.

The individual scientific society could set up requirements which are measured by a tangible scoring of accomplishments in the particular field of the society. The scoring should be more liberal in order to place it within reach of young engineers in a reasonable time and thereby maintain and stimulate his interest and pride in his profession and technical society.

The name of the degrees probably would have to be coined by the joint scientific societies committee because of existing names for degrees. For example, doctor of science would be the proper title for the main scientific degree, but there are many doctor of science degrees in existence which would not meet the more rigid requirements.

The one basic requirement for any degree scoring would be a bachelors degree in some science. Then the scoring for the main degree would be along these lines with (8) a requirement:

1. College masters degree = 1 point.
2. College doctors degree = 2 points.
3. College instructor of a science subject = $^1/_5$ point per year, 10 points maximum.
4. Issued patent = 1 point for one invention, 10 points maximum.
5. Published technical paper approved by a scientific society for a degree count = 1 point for one paper, 10 points maximum.
6. Member of a scientific society = 1 point total.
7. Three recommendations from degree men in two scientific societies = 1 point.
8. Degree from a scientific society = 1 point total.

Possession of 12 points would permit an application to be filed with the joint scientific societies committee for approval and issuance of the degree or issuance by a college.

Scoring of intangible services must be avoided since we want to give recognition to the professional man who by personal effort has contributed something tangible and direct to his profession, the public, and industry.

Too much is expected of young men with their doctor's degree, and young men with a doctor's degree resent being supervised by a man with a bachelor's degree. So let us lift the profession to a higher plane by setting up degree requirements which compel universal acceptance and honor.

CARL G. JONES (A '16, M '18)

(Special engineer, Youngstown Sheet and Tube Company, Youngstown, Ohio)

Industrial Research Under Free Enterprise

To the Editor:

It seems to me that *Electrical Engineering* is lowering itself and inviting disunity amongst the membership by allowing itself to become a medium for political controversy. I refer specifically to the article by Mr. Ruthenberg in the June issue in which he refers to "political meddling, restriction, and persecution of American business" and "a remarkable river named the Tennessee which runs through Tennessee but drains all 48 states." I think you will agree that the latter statement would be extremely distasteful to a TVA member of AIEE and would cause him to wonder why he was contributing to such an attack upon his own organization.

The statement that the Institute assumes no responsibility for the expressions of contributors theoretically makes everything all right, but practically it does not.

In the interests of unity, I respectfully suggest that you disallow the insertion of controversial political statements in articles unless the membership as a body takes a stand on the questions involved.

DONALD G. WORTH (A '32, M '40)

(Senior electrical engineer, Bonneville Power Administration, Washington, D. C.)

To the Editor:

Mr. Louis Ruthenberg, whose address appears in the June 1944 issue of *Electrical Engineering*, pages 210–15, entitled, "Industrial Research Under Free Enterprise," cites eminent authority as to the tremendous savings made by inventions.

Doctor Pupin is quoted as stating that certain of his inventions saved the public $100,000,000, and other instances might be cited. For example, no one could begin to estimate the enormous savings made by the vacuum tube of Doctor Lee De Forest. Doctor Pupin points out that he personally got only a microscopic part of this saving, and Doctor De Forest could say the same thing.

Mr. Ruthenberg has very well presented particular instances of a general law, which is that no inventer ever can receive from the general public more than the public thinks his invention is worth. The inventer makes a bargain with the Commissioner of Patents under which the inventer allows the Commissioner to publish the inventer's secret in return for a limited monopoly. The issue of the patent, however, does not insure in any way that the inventer ever will make any profit from his invention. For the inventer to get anything, embodiments of his invention must be sold to the public, and the public will not buy unless the invention is sold at a price that will enable the public to make a profit or saving from the use of the invention after paying the inventer his usually small stipend. It must be more profitable to the public to use the invention than to use anything that has gone before, and the inventer can collect profit from his invention only if and as long as the public profits from its use. He, however, can collect for only a limited period, and Doctor Pupin long ago ceased to collect anything from his valuable inventions, which are still in general use. Doctor Pupin and many other inventers have made perpetual gifts to civilization for short-lived and small rewards. Of course, we all realize that no inventer now can hope to receive a large award as he must reckon with surtaxes, which now start at about bare subsistence levels. We make ability in invention, just as we make business ability, a misdemeanor punishable by fines which are graduated so that the more ability a man has, the heavier the fine.

The fundamental equities of the patent system are so strong that it has come through a period of muddled public thinking without serious damage in spite of vicious attacks by the radical socialists who are at least fellow travellers with some people in high places.

The Kilgore Bill, to which Mr. Ruthenberg refers, is a good example of what the Socialists would do if they could, and it is quite significant that no one eminent in applied science has approved it. A geneticist, anthropologist, or astronomer may look with favor on Government subsidies and Government control, but no engineer as yet has shown any enthusiasm for a WPA for scientists and engineers.

There is a lull in the Socialist's program due to the war, but this program is dormant, not dead, and we can expect that it will be revived as soon as the stress of war diminishes. Mr. Ruthenberg's address is therefore well timed.

FORD W. HARRIS (A '06, F '13)

(Senior partner, Harris, Kiech, Foster, and Harris, Los Angeles, Calif.)

To the Editor:

Please consider this as my protest against the series of articles recently published concerning the Kilgore Bill. I consider the article by Louis Ruthenberg to be in bad taste. It lowers the standard of the publication.

If you are to avoid another outburst of the old accusation that the AIEE is run for and by a small coterie of men who are subservient to the National Electrical Manufacturers Association, you can do no less than grant space to a member who is sympathetic with the New Deal and labor so that suitable answer can be made.

If you officers at headquarters only could know the undercurrent of revolt which is active among the rank and file of the members, you would broaden the outlook of the publication.

ROY C. DWYER (A '39)

(Engineer, Aluminum Company of America, Riverbank, Calif.)

EDITOR'S NOTE. The feature article columns of *Electrical Engineering* are always open to significant material on any topic in its field or on closely related subjects. Rather than shun any subject because it is of a controversial nature, it has been the policy to publish material reflecting significant aspects of such controversial subjects as fall within the field.

PAMPHLETS . . .

Postwar Employment and the Liquidation of War Production. Committee for Economic Development, 285 Madison Avenue, New York 17, N. Y., 23 pages, no charge.

Fiscal and Monetary Policy. Beardsley Ruml and H. C. Sonne. National Planning Association, 800 21st Street, N. W., Washington 6, D. C., 41 pages, 25 cents.

Evaluating Apprentices. Apprentice-Training Service, Bureau of Training, War Manpower Commission, Washington, D. C., 20 pages, no charge.

Fleet-Welding. Lincoln Electric Company, Cleveland 1, Ohio, 48 pages.

Distribution—The Bottleneck to Farm Electrification. By Frank E. Watts. *The Farm Journal*, Washington Square, Philadelphia, Pa., 30 pages.

Nitrocellulose. Hercules Powder Company, Wilmington 99, Del., 54 pages.

A Summary of Data on Synthetic Rubber. The Rubber Manufacturers Association, 444 Madison Avenue, New York 22, N. Y., 36 pages.

Reproduction Manual. The Multi-Color Company, 629 Woodward Avenue, Detroit, Mich., unpaged, $5.

NEW BOOKS . . .

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Physical Chemistry of Electrolytic Solutions. (American Chemical Society Monograph Series 95.) By H. S. Harned and B. B. Owen. Reinhold Publishing Corporation, New York, N. Y., 1943. 611 pages, illustrated, 9½ by 6 inches, cloth, $10. (ESL.)

The first five chapters deal with general thermodynamics, the basic interionic attraction theory, and ionic solutions in equilibrium and in perturbed states. There is a numerical summary. The succeeding five chapters comprise a discussion of experimental methods for the study of electrolytes. The last five chapters cover the properties of electrolytes such as hydrochloric acid, 1–1, and polyvalent electrolytes, with the last two chapters considering, respectively, the strong and weak electrolytes.

Principles of Electrodeposition. By S. Field. Sir Isaac Pitman and Sons, London, England; Pitman Publishing Corporation, New York, N. Y., 1944. 314 pages, illustrated, 9 by 5⅓ inches, cloth, $6. (ESL.)

This volume provides a simple treatment of the principles of electrochemistry that are of interest to electroplaters and electrorefiners. The treatment is nonmathematical and emphasizes industrial and experimental viewpoints.

Public Rural Electrification. By F. W. Muller. American Council on Public Affairs, Washington, D. C., 1944. 183 pages,

tables, 9 by 6 inches, paper, $2.50; cloth, $3. (ESL.)

This is a report on the development and present status of rural electrification in this country, with some attention to the future. The functions, organization, and general character of the Rural Electrification Administration and of local co-operative systems are discussed as well as their relationships in regard to control and planning.

Railway Fuel and Traveling Engineers' Association. Seventh annual proceedings, 1943. Railway Fuel and Traveling Engineers' Association, 327 South La Salle Street, Chicago 4, Ill. 206 pages, illustrated, 9¼ by 6 inches, cloth, $3. (ESL.)

The proceedings contain the reports of the officers and of various committees and discussions on gas-turbine locomotives, firing practice, Diesel locomotives, coal firing, and the utilization of motive power. There are also papers on efficiency and economy in steam-locomotive operation and on fast-freight braking.

Tables for Converting Rectangular to Polar Co-ordinates. By J. C. P. Miller. Dover Publications, New York. Reprint of 1939 publication, 16 pages, tables, 9¾ by 6 inches, paper, 75 cents. (ESL.)

These tables, which are intended for use with a calculating machine or slide rule, will be found useful by electrical engineers and others.

Tables of Lagrangian Interpolation Coefficients. Prepared by the mathematical tables project, Work Projects Administration of the Federal Works Agency; conducted under the sponsorship of the National Bureau of Standards. Published by Columbia University Press, New York, N. Y., 1944. 392 pages, tables, 10¾ by 8 inches, cloth, $5. (ESL.)

This volume extends the existing tables of Lagrangian interpolation coefficients in n-point polynomials for $n = 3, 4, \ldots, 11$ by giving the entries at smaller intervals of the argument and by making adequate provision for interpolation near the beginning and near the end of the table. All the coefficients of Everett's central difference formula, as well as several other special types, are identical with certain Lagrangian coefficients given in this table. The main group consists of eight- to ten-place tables.

Abbrevs. (A dictionary of abbreviations.) Compiled by H. J. Stephenson. Macmillan Company, New York, N. Y., 1943. 126 pages, 8½ by 5½ inches, cloth, $1.75. (ESL.)

This dictionary brings together a great number of abbreviations commonly met in books and papers and frequently puzzling to the reader. Literary, scientific, and industrial fields are covered.

Life of Sir J. J. Thomson. By Lord Rayleigh. University Press, Cambridge, England; Macmillan Company, New York, N. Y., 1943. 299 pages, illustrated, 9 by 5½ inches, cloth, $6. (ESL.)

Lord Rayleigh has written an excellent account of the life of the great physicist, in which is reviewed the epoch-making scientific work done at the Cavendish Laboratory by Thomson and his pupils. The human side of the man also is covered. Laymen as well as scientists will find the book full of interest.

Mathematics of Radio Communications. By T. J. Wang. D. Van Nostrand Company, New York, N. Y., 1943. 371 pages, illustrated, 9 by 5½ inches, fabrikoid, $3. (ESL.)

This textbook was written to facilitate the study of radio, electronics, and so forth, by providing a course in mathematics integrated with one in communications, the subjects being interwoven so that each electrical topic is preceded by the requisite mathematics. The book is designed especially for use in accelerated programs.

Quantitative Analysis. By H. S. Booth and V. R. Damerell. Second edition. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. 303 pages, illustrated, 8½ by 5½ inches, cloth, $2.50. (ESL.)

This elementary textbook covers the course of practical work usually given beginners and is adapted either for a half-year or a year course. The directions are clear and explicit.

Basic Radio. By C. L. Boltz. Ronald Press Company, New York, N. Y., 1944. 272 pages, illustrated, 8 by 5 inches, cloth, $2.25. (ESL.)

"Basic Radio" is based on the syllabus for British air training cadets, and forms an interesting contrast to the similar books published for use in the United States Army. It presents an elementary course in fundamentals and is exceptionally clear and simple.

Industrial Management. By A. S. Knowles and R. D. Thomson. The Macmillan Company, New York, N. Y., 1944. 791 pages, illustrated, 8½ by 5½ inches, cloth, $4.50. (ESL.)

The subject matter of this book is confined to topics of immediate concern to persons who must direct the work of others in manufacturing enterprises. The six main divisions are: introduction; management of physical property; organization of the physical plant; management of man power; production control; and cost control. Such topics as time and motion study may appear under two or more headings if pertinent. Practical problems representing actual situations are included.

Fundamentals of Vibration Study. By R. G. Manley with a foreword by W. K. Wilson. John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1942. 124 pages, illustrated, 9 by 5½ inches, cloth, $2.75. (ESL.)

Fundamental principles underlying present-day vibration study are presented in such a way as to be readily assimilated by the busy engineer. Major topics considered are the physics of the simple vibrating system, damping and forced vibration, systems with two or more degrees of freedom, and the application of Fourier's analysis to complex vibrations.

Fundamentals of Radio Communications. By A. R. Frey. Longmans, Green and Company, New York, N. Y., London, England, Toronto, Ont., 1944. 393 pages, illustrated, 8½ by 6 inches, cloth, $4. (ESL.)

In this book an effort has been made to present the fundamentals of the subject as concisely as possible. In accordance with this desire, the aim has been to familiarize the student with the terminology of radio, with the more important types of circuits, and with the ways in which vacuum tubes can be used to generate, control, and detect the high-frequency currents that are used. References are supplied for further study of various subjects.

From a Chemist's Diary. (Kansas City Testing Laboratory Bulletin 29.) By R. Cross. Kansas City Testing Laboratory, Cross Laboratories, Kansas City, Mo., 1943. 315 pages, illustrated, 9 by 6 inches, cloth, $3. (ESL.)

This book is a collection of random items from the diary of the writer, a consulting industrial and research chemist. They have been selected for their interest for the person not specially trained in chemistry or science and technical details have been kept to a minimum. The wide range of topics covers meteorology, earthquakes, the patent system, and octimal arithmetic as well as sidelights on many applications of chemical analysis.

Technique of Motion Picture Production. Published for the Society of Motion Picture Engineers by Interscience Publishers, New York, N. Y., 1944. 150 pages, illustrated, 9½ by 6 inches, cloth, $3.50. (ESL.)

This volume contains 11 papers presented at a convention of the Society of Motion Picture Engineers. These papers describe current technical practice in motion-picture production, with production stages arranged in the order generally followed in producing and presenting motion pictures. The book combines much information that has not been accessible heretofore in a logical convenient form.

Theorie und Anwendung der Laplace-Transformation. By G. Doetsch. Dover Publications, New York, 16, N. Y., 1943. 439 pages, illustrated, 9½ by 6 inches, cloth, $3.75. (ESL.)

This reproduction of Doetsch's classic monograph makes it available in this country at a price very much below the original one. The book, first published in 1937, provides a comprehensive descriptive analysis of the theory and mathematical foundations of the Laplace transformation and its practical application to problems of physics and electrical engineering. A German–English glossary has been added to the reprint.

Diesel Locomotives. By J. Draney. American Technical Society, Chicago, Ill., 1944. 388 pages, illustrated, 8½ by 5½ inches, cloth, $3.75. (ESL.)

A simple practical text on the operation and maintenance of the electrical equipment of Diesel locomotives. The equipment of the Baldwin-Westinghouse, Electro-Motive, and Alco-G.E. locomotives is described in detail.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

A-C Contactors for Aircraft

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Synopsis: Use of a-c power systems on aircraft presents the problem of providing switching means. Contactors with the desired characteristics and suitable size and weight have not been available. Analysis of operating conditions, contactor size requirements, and performance characteristics provide a basis of design of a group of contactors to meet the needs of present and projected aircraft. These designs can meet aircraft size limitations and be capable of handling the circuits under all foreseen normal and emergency requirements.

PRESENT and projected designs of aircraft have electric-system requirements which far exceed in capacity those used in the past. As the airplanes have become larger, the electrically operated auxiliaries have required more and more power. Early airplanes had six-volt d-c systems, but these were quickly found to be inadequate because of excessive drop in the conductors. In order to avoid the use of prohibitively heavy cables, the voltage was increased to 12 and finally to 24 volts. Power requirements have continued to rise since the last increase in voltage, and a point again has been reached where a change in the electric system is considered necessary. A number of possibilities have been suggested.[1] One of these is the use of a-c generators with constant-voltage output at constant frequency with most of the power being used as generated but with a portion of it being rectified for use with d-c instruments and in control circuits. Many points in favor of this system have been advanced.[2]

Use of alternating current makes it necessary to provide suitable switching equipment for controlling the circuits. Relays and contactors used in d-c systems are nearly all single-pole low-voltage devices and are not satisfactory for use on three-phase a-c systems. While all of the devices needed are available in commercial form, their design is such that they are not satisfactory for use in aircraft. Their size and weight is excessive, and they are not designed for use under the wide range of conditions normal to aircraft operation.

Contactor Requirements

Design of the contactors needed involves a study of the factors influencing their operation. These include characteristics of the power system; type of load and duty cycle; as well as temperature, humidity, pressure, vibration, shock, dust, and other conditions to which they might be subjected.

Magnetically operated relays and contactors are used for the following purposes:

1. To shorten the power-carrying lines by running them only to the point of use.
2. To make possible automatic-control functions.
3. To save space at the control stations by the use of small pilot switches.
4. To keep high voltage from control stations by using low-voltage control circuits.

Alternators, driven by the main engines, furnish the principal source of power. The system is 208 volts, 400 cycles, three-phase with grounded neutral. In one proposed arrangement the main bus is a loop with sectionalizing contactors, so arranged that a fault may be isolated and removed with minimum disturbance to the remainder of the system. The alternators feed this loop through latched contactors arranged to trip on a fault in the feeders or in the machines themselves. Loads are fed from the main bus either directly or through branch bus systems. Contactors for connecting the loads are required. In some cases some of the branch systems may be transferred to an auxiliary power supply, in which case transfer switches are used.

If it should prove to be impractical to operate the alternators in parallel on a common bus, it is proposed to supply some of the loads from each of the alternators with provision for transferring in case of emergency. Transfer switches of suitable rating are required to perform this function.

The latched contactors function as circuit breakers operated by separate protective relays not part of the contactor itself. Separation of the protective devices from the main contactor is made in the interests of simplification of the devices and in order to increase interchangeability, since the same contactor may then be used with various circuit protective relays to obtain different types of protection or with manual control for sectionalizing the system.

The greater part of the load consists of motors. All motors are intended to in-

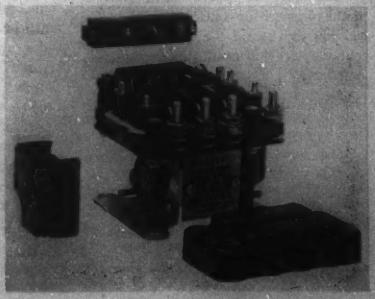

Figure 1. Three-pole single-throw contactor rated 25 amperes, 208 volts, 400 cycles

The covers and moving-contact assembly have been removed to show construction

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Figure 2. Three-pole double-throw 25-ampere contactor

corporate built-in overload protection, making provision of overload elements as part of the contactor or starting switch unnecessary.

Contactors of several types and ratings are required to perform various functions:

1. Single-pole single-throw for closing and opening single-phase load circuits—25 amperes continuous rating.

2. Single-pole double-throw for transferring circuits—25 amperes continuous rating.

3. Three-pole single-throw for closing and opening three-phase load circuits—5, 25, 50, and 100 amperes continuous rating.

4. Three-pole double-throw for reversing, motor-starting, and transfer of circuits—5, 25, 50, and 100 amperes continuous rating.

5. Three-pole latched for main circuit and alternator disconnects and for circuit protection—120 amperes continuous rating.

In addition to carrying rated full-load current, contactors must be capable of opening and closing the inrush currents which will be obtained with various types of loads. Under emergency conditions, the stalled current of motors may have to be interrupted. Current requirement under these conditions has been established as ten times full-load rating.

Temperature, vibration, and acceleration requirements have been discussed at length in connection with other aircraft equipment. Experience has indicated that in addition greater attention needs to be given to enclosures and protection against the effects of high humidity and the entrance of dust.

D-C Control Circuits

Availability of direct current as a source of power for control circuits makes possible the use of d-c magnets in the contactors. This results in certain advantages:

1. Magnets can be smaller, lighter, and more rugged than if they were made for operation on 400 cycles alternating current.

2. Switches now being used for the control of circuits and contactors in d-c systems can be used, making possible instrument panel layouts similar to those used in d-c systems.

3. Replacement problems are simplified.

4. Many of the present control schemes are usable.

5. High voltages which might be hazardous to operating personnel are removed from the pilot switches.

When automatic control from the a-c circuits is required, small rectifiers may be used to supply the d-c magnets.

Insulation

Use of three-phase circuits requires the use of three-pole contactors, introducing insulation problems in that it is necessary to insulate the a-c and the d-c circuits from each other and from ground, as well as to obtain phase isolation, all in the same device. In commercial practice, the idea of "phase spacing" is frequently synonomous with phase isolation, but in the design of aircraft contactors it is not practical to approach the problem from this point of view. It is not possible to space the poles sufficiently to obtain the required insulation distances without exceeding the space and weight limitations imposed on this apparatus. This problem is complicated further by the need for protection against the entrance of dust, a serious condition when operating on desert airfields, and by the effect of rarified atmospheres on insulation breakdown,[2] since the equipment must be suitable for operation at altitudes up to 40,000 feet. It therefore becomes necessary to obtain phase isolation by providing suitable barriers between poles and to provide an enclosure to prevent the entrance of dust. One of the principal causes of failure in circuit-interrupting devices is flashover between poles due to the presence of ionized gases. There are several ways in which this problem may be overcome:

1. Sufficient space may be provided between poles to limit the ion concentration to a value at which flashover does not occur, a method which is not economical as to space and weight.

2. A sufficiently long path may be provided between poles in which the gases are in contact with cold surfaces so that deionization takes place.

3. The contacts may be placed in closed pockets which prevent the gases from coming into contact with parts of opposite polarity. Provision for venting the gases while maintaining a suitable dust seal may be required.

The last method is the only one which permits the contacts to be sealed to prevent the entrance of dust or other foreign material which might interfere with operation or which would cause insulation failure. It has the disadvantage that, in order to obtain the best space factor in the switch design, the arc is in close proximity with the insulation material. Failure may occur because of insulation breakdown, unless a material is used which has high resistance to arc tracking. Melamine formaldehyde insulation materials have this property and provide a suitable answer to this problem.

Figure 3. Single-pole single-throw 25-ampere contactor

Arc Interruption

The contactors must be capable of making and breaking the current which may exist under any condition encountered in operation. Under normal conditions, this may be the rated current or less, or the current at the instant the contacts close may be much higher, dropping quickly to the steady current. The contacts therefore must be capable of making ten times the rated current and breaking rated current as a normal condition, that is, for the life of the contactor. Under emergency conditions, the contacts may be called upon to open the same high current for a limited number of operations in order to clear faulty circuits or apparatus. In general, no difficulty is experienced with alternating current in breaking high current at the voltage used on these systems, even with relatively small arc gaps. The gap is determined by the distance required to prevent flashover at the maximum voltage used for insulation testing, in this case 2,500 volts at sea level and 1,000

volts at 40,000 feet altitude. Breaking high current may damage the contacts so as to reduce their life considerably or, in extreme cases, cause failure when the switch is again closed. Closing of the circuit presents a more serious problem, because, when closing on high currents, the contacts are liable to weld. Factors involved in this case are the current on which the contacts close, the material or materials of which the contacts are made, and the amount of arcing obtained during closure—the latter being determined by the mass of the contacts, their velocity and the forces involved: that is, the initial contact pressure and the magnet pull. The design must be such as to obtain the proper relationship of these factors to limit the rebound to as small a value as possible. Use of the contact materials which are not readily welded offers many possibilities, but care must be exercised to keep their resistance low. If the contacts are to be enclosed in relatively tight chambers for obtaining phase isolation and for protection against the entry of foreign materials, the enclosure must be made sufficiently strong to prevent breakage under the relatively high pressures built up when the arc is broken, or some provision must be made to permit the pressure to be relieved.

Figure 4. Three-pole double-throw five-ampere contactor

Arrangement

Two general contact structures are available. The moving contacts may be carried on a pivoted arm which is in turn operated by the magnet. In this form, the contacts are generally single break and have flexible connections to carry the current to the moving part. For high current values the connections must be quite large and heavy, so that in order to retain flexibility they are made relatively long. It was thought that a better choice for the larger-size contactors would be the use of bridging-type contacts. Figure 1 shows the arrangement of the contacts and terminals and is typical of three-pole contactors rated 25 amperes and higher. The contact cover and the terminal covers have been removed and the moving contact assembly lifted out. All stationary contacts are fastened to a molded insulating board with barriers to separate the phases. The moving contacts with their springs are carried in a sliding insulator assembly which is guided in a slot formed by the barriers provided between the stationary contacts. The barriers are designed to fit into recesses in the contact cover in such a manner that each contact is an individual chamber formed by the barriers, the slider, and the cover. While the closure between chambers is not absolutely sealed, the connecting spaces are very narrow and of such length that the gases are deionized before passing from one to the other. A seal against the entrance of dust is obtained by use of a compressible heat-resisting gasket between the edges of the cover and the base. Covers are provided over the terminal screws to prevent accidental contact by personnel or by objects which might fall across them. The sliding contact member is actuated by a pivoted lever, one end of which fits into the sliding bar and the other end of which is connected to the solenoid plunger. The contact bar and the solenoid plunger form a balanced structure which has essentially the same mass on each side of the pivot and is therefore unaffected by acceleration forces, making the device insensitive to shock and vibration. On double-throw contactors two similar contactors are mounted side by side on a common base as shown in Figure 2. A pivoted mechanical interlocking bar prevents one plunger from pulling in to close the contacts associated with it if the other plunger is already in its sealed position. Suitable covers with sealing gaskets protect the mechanism from mechanical interference and the entrance of dust.

The smaller-rating contactors are readily adapted to the pivoted armature construction and accordingly are made in this form. Figure 3 is typical of the construction used and shows a 25-ampere single-pole single-throw contactor. A single bridging contact is used in this case, whereas on the three-pole contactor single-break finger-type contacts with flexible connectors are used. Double-throw contactors consist of two contactors mounted on a common base and mechanically interlocked to prevent simultaneous operation. Figure 4 shows a five-ampere three-pole double-throw contactor.

Contacts of the latched contactor are of the bridging type. The arrangement is similar to that used on the larger three-pole switches. The closing magnet consists of a solenoid which pulls the contacts into the closed position where they are held by a latch operating on the lever which moves the contact bar. The magnet coil is disconnected as soon as the contacts reach their sealed position by means of a single-pole double-throw switch operated from the contact bar. Sufficient overtravel of the contacts beyond the normal wear allowance is provided, so that the coil disconnect switch does not operate until after full latch engagement is obtained. This must be done to prevent the possibility of failure of the contacts to latch under low coil voltage. The coil switch also is connected in the circuit of the trip coil so that, when the main contacts are in the closed position, the trip coil may be energized to permit the main contacts to open. Intermittent-duty coils are energized only long enough to close or open the main contacts. In order to prevent "telegraphing," the operating and latch mechanism is arranged to prevent the

Figure 5. Three-pole latched contactor

Rated 120 amperes continuous with 4,000-ampere short-circuit capacity

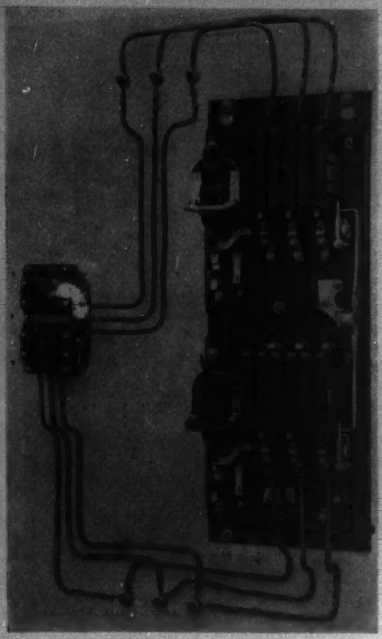

Figure 6. Three-pole double-throw aircraft contactor and comparable commercial contactor

materials enables contactors to be built which are much smaller and lighter than their commercial counterparts. This is illustrated in Figure 6 which shows a 50-ampere three-pole double-throw aircraft contactor and a commercial contactor of the same rating. It should be noted that the commercial device is open whereas the aircraft contactor is completely enclosed.

Figure 7 shows all of the contactors designed to meet the needs of aircraft a-c electric systems. They include single-pole single- and double-throw contactors rated at 25 amperes; three-pole single- and double-throw contactors for 5, 25, 50, and 100 amperes; and a 120-ampere three-pole latched contactor or circuit breaker. Performance in each case meets the anticipated conditions which might be encountered in a-c systems used on aircraft and, with the exception of life, which for aircraft applications is much lower than required in commercial applications, either meets or exceeds the conditions required on the equivalent commercial contactor.

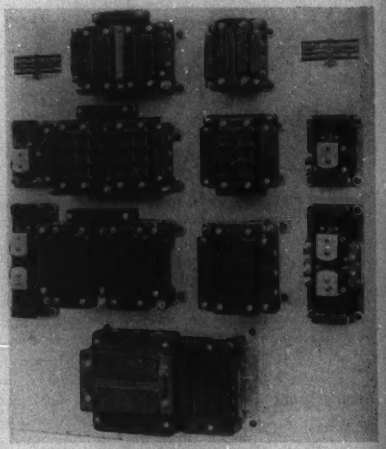

Figure 7. Various sizes and types of contactors required on large aircraft with a-c electric systems

closing magnet from closing the contacts following energization of the trip magnet until the closing-coil circuit has been opened. The contactor is "trip-free," that is, it cannot be held closed when the trip circuit is closed. Additional contacts are provided for electrically interlocking other circuits. Figure 5 shows the construction used in this contactor.

In order to protect other apparatus in the circuit, the fuses and the latched contactors must be co-ordinated in design to provide the proper protection from each under fault conditions. Accordingly, a specification has been established requiring that complete current interruption take place within 0.01 second after the trip impulse has been initiated. This time includes the arcing time and the time required for the contacts to begin to part. The worst condition which might be encountered is on single-phase where the arc might persist for one-half cycle plus the time required for the contacts to reach a gap great enough to prevent the arc from restriking. On 400 cycles this time will be something less than 0.002 second. The contacts must separate in 0.008 second or less after the trip-coil impulse is started. Results indicate that this time can be met satisfactorily.

Summary

Requirements for aircraft contactors may be summarized briefly as follows.

1. Small size and low weight.
2. Resistance to vibration and shock incident to their use on aircraft.
3. Ability to operate under a wide range of temperature, humidity, and pressure.
4. Enclosures to exclude dust from contacts and mechanism.
5. Ability to handle normal and emergency load conditions.
6. Confinement of arc within the device.

Analysis of these requirements and design to obtain maximum utilization of

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2. Why Tomorrow's Planes Will Have A-C Systems, T. B. Holliday. *Electrical Manufacturing*, volume 32, July 1943, page 88.

3. Potential Breakdown of Small Gaps Under Simulated High-Altitude Conditions, M. J. De Lorno. AIEE Transactions, volume 63, 1944, March section, pages 109–12.

Industrial Control—Shunted-Armature Connection for a D-C Shunt Motor

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THERE are many operations in applications where d-c shunt motors are used where it is necessary to slow down the rotating system in order to perform certain functions. Many typical examples are found in machine-tool work, such as cross-feeding of a tool, milling-cutter slow-down for sharp corners, accurate positioning of tool to work, slow-down of a grinding wheel for dressing. Other examples are found in the slowing down of a printing machine for the purpose of matching colors and occasionally to obtain a threading speed in a textile range drive.

There are three common methods by which these slow-down speeds may be obtained:

1. Resistance inserted in series with the armature is a method of slowing down a motor but has the disadvantage that the speed will vary considerably for slight changes in the torque demanded by the load, so that this method has poor speed regulation.

2. Variable-voltage control is a circuit in which the generator field is adjusted to vary the armature voltage, while the motor field is left constant. This method gives a range of speeds up to basic speed with good speed-torque regulation and good efficiency but is inherently too costly for intermittent applications such as were mentioned previously.

3. If resistance is put in parallel with the armature in addition to series line resistance, a method of control known as the shunted-armature connection is given. This method provides good speed regulation at low initial cost and is ideally suited for short-time or intermittent slow-downs, despite the decreased efficiency due to losses in the shunt resistance. The method is in effect a potentiometer connection (see Figure 1).

Scope of Paper

This paper presents a simple graphical method of obtaining the required shunt and series resistances for the shunted-armature connection to obtain any desired speed at a specified value of torque and also to give a predetermined no-load speed. An analytical verification of the graphical method is also presented.

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The method is outlined for the cases of a constant-speed motor and an adjustable-speed motor.

Nomenclature

I = line current in amperes
V = line voltage in volts
R = series resistance in ohms
S = shunt resistance in ohms
E = back electromotive force in volts
I_s = current through shunt resistance
I_a = armature current in amperes
R_a = armature resistance in ohms
N = speed in rpm
E_o = back electromotive force in volts when $I_a = 0$

All lower-case letters refer to the per unit value of the aforementioned quantities.

T = torque in foot-pounds
T = per unit torque

The subscript FL refers to the full-load condition in the motor. The subscript NL refers to the no-load or running-light condition when full voltage V is applied.

$R_o = V/I_{FL}$ = base or normal ohms
n_o = rpm in per unit when $i_a = 0$

Analysis

Constant-Speed Motors

Application of Kirchoff's laws to the circuit shown in Figure 1 yields the equations,

$$I = I_a + I_s \tag{1}$$
$$V = IR + E + I_a R_a \tag{2}$$

and

$$I_s S = E + I_a R_a \tag{3}$$

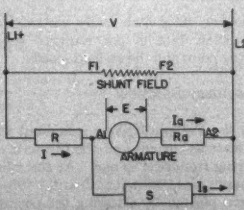

Figure 1. Elementary diagram for the shunted-armature connection showing shunt and series resistance

If equations 1, 2, and 3 are solved simultaneously, a relationship between the armature current and the counter electromotive force is given as a function of the circuit resistances. The resulting equation is

$$I_a\left[R_a\frac{(S+R)}{S}+R\right]=V-E\frac{(S+R)}{S} \tag{4}$$

The intercepts of equation 4 are given by putting $I_a = 0$ and $E = 0$. They become:

$$I_a=\frac{V}{R_a\frac{(S+R)}{S}+R} \tag{4a}$$

and

$$E_o = V\frac{S}{S+R} \tag{4b}$$

Equation 4 represents a straight line on the axes of armature current as the ordinate and counter electromotive force as the abscissa.

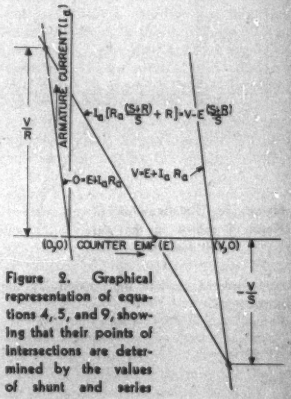

Figure 2. Graphical representation of equations 4, 5, and 9, showing that their points of intersections are determined by the values of shunt and series resistance

Let equation 4 be solved simultaneously with the motor equation,

$$V = E + I_a R_a \tag{5}$$

to find the point of intersection.

Substitution of $E = V - I_a R_a$ from equation 5 into equation 4 gives

$$I_a\left[R_a\frac{(S+R)}{S}+R\right]=V-(V-I_aR_a)\frac{(S+R)}{S} \tag{6}$$

which reduces to

$$I_a R = V\left[1-\frac{S+R}{S}\right] \tag{7}$$

so that, at the point of intersection,

$$I_a = -V/S \tag{8}$$

Now, if equation 4 is solved simultaneously with the straight-line equation,

$$0 = E + I_a R_a \tag{9}$$

the point of intersection becomes

$$I_a = V/R \tag{10}$$

This shows that, if equations 4, 5, and 9 are plotted on the same co-ordinates of I_a and E, their points of intersection are determined by the values of shunt and series resistance. These relationships are shown in Figure 2.

Per Unit System

Let line voltage V be 100 per cent or base voltage, full field current I_{FL} be

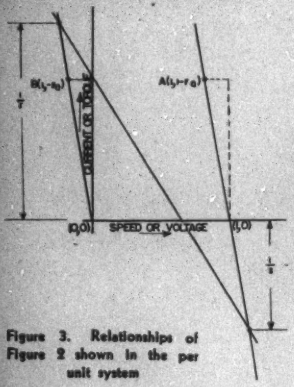

Figure 3. Relationships of Figure 2 shown in the per unit system

base current, and no-load speed N_{NL} be base speed.
Since

$$T = c\phi I_a \tag{11}$$

and

$$E = K\phi N \tag{12}$$

then, by eliminating ϕ from equations 11 and 12,

$$T = \frac{c}{K}\frac{EI_a}{N} \tag{13}$$

and

$$T_{FL} = \frac{c}{K}\frac{E}{N}I_{FL} = \frac{c}{K}\frac{V}{N_{NL}}I_{FL} \tag{14}$$

since the back electromotive force equals line voltage at no-load speed. Therefore, base torque is full-load torque which is consistent with the aforementioned base quantities of voltage, current, and speed.

In this per unit system,

Per unit volts $e = E/V$

Per unit current $i = I/I_{FL}$

Per unit speed $n = N/N_{NL}$

Per unit torque $T = T/T_{FL}$

Also,

Normal ohms $R_a = V/I_{FL}$

so that

Per unit ohms = ohms/R_a

If equations 11 and 12 are put into the per unit system,

$$T = i_a \tag{15}$$

and

$$e = n \tag{16}$$

Figure 3 is obtained by transposing Figure 2 into the per unit system and using torque and speed as co-ordinates alternately with current and voltage as permitted by equations 15 and 16.

Equations 5 and 9 in the per unit system become

$$1 = e + i_a r_a \tag{17}$$

$$0 = e + i_a r_a \tag{18}$$

If i_a is put equal to unity in equations 17 and 18 to find the co-ordinates of two points A and B in Figure 3, $A\ (1, 1-r_a)$ and $B\ (1, -r_a)$ are yielded, so that equations 17 and 18 are determined only by the value of internal resistance in per unit at the unity-current point.

Equation 4 in per unit is

$$i_a\left[r_a\frac{(s+r)}{s} + r\right] = 1 - e\frac{(s+r)}{s} \tag{19}$$

When i_a equals zero, equation 19 becomes

$$e_o = \frac{s}{s+r} \tag{20}$$

From equation 4b:

$$\frac{S}{S+R} = \frac{E_o}{V} = \frac{E_o}{E_{NL}} = \frac{N_o}{N_{NL}} \tag{21}$$

Now,

$$\frac{E_o}{V} = e_o$$

and

$$\frac{N_o}{N_{NL}} = n_o$$

so that $e_o = n_o$ from equation 21, and the intercept on the x axis is

$$n_o = s/(s+r)$$

Equation 19 is then easily plotted from the given data of one required speed-torque point and the no-load speed.

Graphical Solution

A sheet of graph paper is laid out with ordinate as current and abscissa as speed varying from zero to one. At the unity-current point, the points B and A (Figure 3) are plotted by knowing the per unit internal resistance of the motor. Through these points and the (0, 0) and (1, 0) points, respectively, straight lines are drawn. From the given data of a speed-torque point (i_a, n) in per unit and the per unit no-load speed required (n_o), a straight line is drawn. The two points of intersection of these three straight lines yield the reciprocals of the shunt and series resistance in per unit.

Example

A machine driven by a ten-horsepower 230-volt 1,150-rpm d-c shunt motor must be slowed down for a short time, so that the shunted-armature connection is indicated. The stated requirement is that the slow-down shall be 45 per cent of the full-load motor speed, and that the speed regulation shall be such that the speed will not exceed 66⅔ per cent of the full-load speed, if all load is removed from the motor shaft. It is given that the load demands 34 per cent of full-load torque, referred to the ten-horsepower motor, at 45 per cent of the motor-rated speed.

Since 100 per cent or per unit speed has been defined as the no-load speed of the motor, the full-load speed can be obtained by subtracting the per unit internal drop from unity. For this size motor the internal resistance is usually taken as ten per cent normal ohms, so that points A and B can be plotted on Figure 4.

The lines drawn through these points and the points (1, 0) and (0, 0) represent the motor characteristics with no added shunt or series resistance.

The 45 per cent speed referred to the no-load speed becomes:

$0.45 \times 0.9 = 0.405$

while the 66⅔ per cent speed becomes:

$0.66^2/_3 \times 0.9 = 0.6$

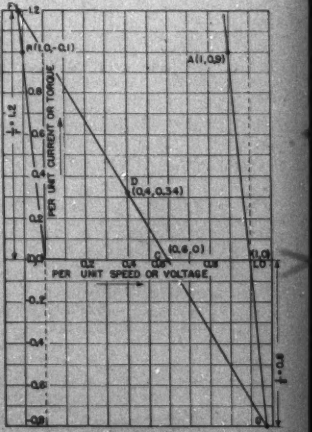

Figure 4. Graphical solution of example presented in the text

This translation of reference speeds from the full-load to the no-load base permits the plotting of the operating points in the per unit system as points C and D, Figure 4. A line drawn through these two points and extended will intersect the motor curves at points F and G. For this particular solution, the ordinates of the points of intersection are $(+1.2)$ and (-0.8). The reciprocal of these two values gives the per unit ohms of the series and shunt resistances, respectively.
Therefore,

$r = 1/1.2 = 0.833$
$s = 1/0.8 = 1.25$

With 100 per cent ohms equal to line voltage V divided by full-load current I_{FL}, the necessary resistances to meet the preceding requirements are:

$R = 230/39 \times 0.833 = 4.91$ ohms
$S = 230/39 \times 1.25 = 7.37$ ohms

Adjustable-Speed Motors

A similar graphical construction can be used to determine the correct resistances for use with adjustable-speed motors. For these motors, load data are usually given with reference to the highest horsepower which occurs at the highest speed. To obtain speed control between highest- and lowest-rated speed, the field current is varied. For speeds below the lowest-rated speed, the armature-shunt connection is used. Therefore, if speeds are referred to this lowest-rated speed as base speed and base torque is full field torque, the graphical solution is identical with that for constant-speed motors. For example, assume that an application using a $7\frac{1}{2}$/10-horsepower 500/1,000-rpm, 230-volt d-c motor must be controlled to give 250 rpm at 80 per cent torque. This latter figure refers to the high speed or weak field torque and is therefore 40 per cent of full field torque. Accordingly, the point which corresponds to D in Figure 4 is plotted at

$$\frac{250\ (0.9)}{500} = 45 \text{ per cent speed and } 40 \text{ per cent torque}$$

Specification of the required speed with no load on the motor shaft, or specification of the speed regulation determines the second point, so that the straight line can be drawn as before.

Conclusion

In many applications the torque demanded by the load is not known very accurately, although the required speed is well defined. The application engineer can compensate for the inaccuracy with which the load torque is known by using the shunted-armature connection and by so choosing a value of shunt resistance to give a good speed regulation. Without a graphical solution, simultaneous equations must be solved analytically. The method previously presented is particularly useful because of its simplicity in obtaining a particular solution as well as determining families of curves that show the effect of shunt and series resistance on the speed-torque characteristics.

Possibilities of Heat Pumps for Heating Homes

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Synopsis: Heat pumps are refrigerating systems in which the principal interest is in the heat given off by the condenser. A portion of this comes from the electric input to the compressor and the remainder from cooling an external source of heat, usually outdoor air. Heat output is several times the equivalent of electric input, and these systems offer possibilities of fuel economy beyond anything possible with fuel-burning equipment. These systems can be used for all-year air conditioning, but the heat requirement dictates larger equipment than necessary for cooling only. Electric-load requirements are attractive, but further development is necessary and will be dependent on the promotion of summer air conditioning for homes.

SOME 92 years ago Lord Kelvin first called to our attention the fact that refrigerating systems are reversible, and that they have some unusual and interesting characteristics when operated as heating systems. Interest in the idea remained very low until about twenty years ago, when the development of the domestic electric refrigerator and commercial refrigeration for food preservation began to make engineers think of summer air conditioning for homes and buildings as something more than just a far-off dream. Since then interest, as judged by technical publications, has steadily increased, and a few actual installations have been made. Practically all of the installations were made before the war and nearly all of them are in successful operation today.

To predict that in the next ten years a substantial proportion of our homes will not be heated by heat pumps seems rash, in view of the rapid development we have already seen in other types of equipment for the home. Therefore, it would appear to be of interest to analyze the prospects as they exist today somewhat sympathetically, even though the way in which widespread use may be obtained is not yet clear.

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Description of a Heat Pump

The heat which a domestic refrigerator absorbs from its cabinet through its evaporator does not just disappear. By means of a mechanical compressor, the temperature of the absorbed heat is raised to the point at which the heat can be transferred to the air outside of the cabinet through its condenser. In so doing it adds to the absorbed heat the heat equivalent of the work done by the compressor, and the sum of the two quantities of heat result as heat added to the room air surrounding the cabinet. When the reason for using the refrigerator is to take advantage of the lowered temperature inside the cabinet, it is called a refrigerator. When the primary object is to heat the surrounding room, it is called a reversed-cycle refrigerator or a heat pump. The type of equipment used in either case is the same. In the case of the heat pump heating a home, instead of placing the evaporator inside of an insulated cabinet, it is more effective to place it in the outdoor air or in a supply of water that can be cooled, and the condenser is usually in the form of a finned coil, with a fan blowing the heated air from the coil through ducts to the house. In any case, the heating of the house air and the simultaneous cooling of the outdoor air or water supply are fundamental to the heat pump, even though the outdoor air being cooled may be at a temperature well below zero.

Figure 1 shows a simplified schematic diagram of a direct-expansion heat pump. When operating in the winter time for heating, air from the house is forced through the condenser, where it is heated sufficiently to satisfy the heat loss of the house. Air from outdoors is forced through the evaporator, where it is cooled sufficiently to provide its contribution of heat to be transmitted to the house.

The liquid refrigerant inside the evaporator is boiled by the heat from the outdoor air at a boiling pressure and temperature sufficiently below the outdoor-air temperature to effect the necessary heat transfer. The compressor draws the refrigerant gas from the evaporator and discharges it to the condenser at a high enough pressure and temperature so that it will condense and transfer its heat to the outgoing house air stream. The expansion valve maintains the pressure difference between condenser and evaporator by regulating the flow of refrigerant through the system. To use this same system for cooling the house in summer, the outdoor air and house air streams are interchanged with dampers, or an equivalent result is accomplished by other means.

If all losses are neglected, the heat output from the condenser of this system is equal to the heat input to the evaporator plus the electric input to the compressor motor. Since the outdoor air is free, the efficiency of the system is the heat output divided by the heat equivalent of the electric input, and because this is always greater than 100 per cent, it is called a coefficient of performance. The electric input multiplied by the coefficient of performance gives the heat output to the house.

Efficiency

The relative proportion of the heat obtained from electric input and from outdoor air depends primarily on the indoor and outdoor temperatures. This is quite different from a fuel-burning furnace, in which efficiency is substantially independent of outdoor temperature. As in the case of a steam-power plant, the heat pump is a heat engine absorbing heat at one temperature level and discharging it at another; the principal difference is that a steam-power plant delivers mechanical work from the engine, whereas the heat pump absorbs it. Both follow a Carnot cycle in the theoretical ideal, and the theoretical ideal efficiencies are similar in form, that for the heat pump being

$$\text{Coefficient of performance} = \frac{T_1}{T_1 - T_2}$$

where T_1 is the house or condenser temperature (both being the same in the ideal) and T_2 is the outdoor or evaporator temperature. Temperatures in this case must be measured on the absolute scale. Curve *A* in Figure 2 shows the coefficient of performance for a perfect Carnot engine heat pump maintaining 70 degrees Fahrenheit in a house at various outdoor temperatures. It will be noted that with a heat pump at 20 degrees Fahrenheit outdoor temperature it is theoretically possible to obtain 10.6 times as much heat in the house as would be possible by using the same power input in electric resistance heaters. In addition to a perfect heat engine this would require condenser and evaporator heat-transfer surfaces sufficiently large to transfer the heat without appreciable temperature differences, and correspondingly large air flows in the house and outdoor air circuits. Sizing the heat-transfer surfaces and air flows to values that would be considered practical in a summer air-conditioning system of similar proportions would give curve *B* in Figure 2, where the refrigerant condensing temperature has been increased and evaporating temperature decreased a total of 60 degrees Fahrenheit. This would permit delivery of heated air to the house at a temperature between 105 to 110 degrees Fahrenheit, which is considerably lower than would be used with a fuel-burning warm-air heating plant, but not enough lower than usual discharge temperatures from a normal year-round residential air-conditioning system to have a prohibitive effect on the cost of fans and duct work.

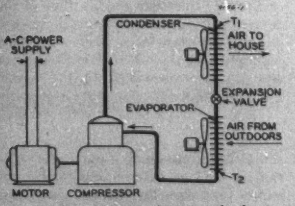

Figure 1. Schematic diagram of elements of a heat pump

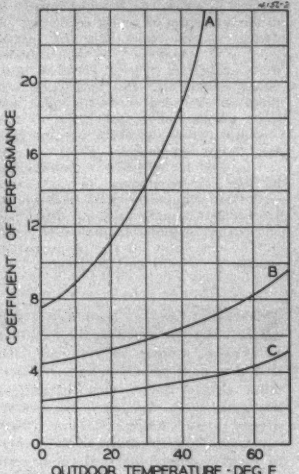

Figure 2. Efficiency characteristics of a heat pump maintaining a house at 70 degrees

Curve *C* in Figure 2 shows coefficients of performance that can be obtained with refrigeration equipment available today. This curve differs from curve *B* in that proper allowance has been made for the use of Freon 12, instead of a perfect refrigerant, for mechanical and other inefficiencies of equipment and for power required by auxiliaries such as fans. The performance indicated by this curve is believed to have been reached by installations now in operation using outdoor air as a source of evaporator heat. It will be noted that in climates such as Pittsburgh or Philadelphia, where less than three per cent of the requirements of the heating season occur at below 20 degrees Fahrenheit outdoor temperature, an average coefficient of performance for the whole heating season of better than three to one can be reasonably expected.

Fuel Economy

At about 52 degrees Fahrenheit outdoor temperature, the realizable coefficient of performance reaches four to one. The best steam-power generating plants today have an over-all thermal efficiency of approximately 34 per cent. Hence, even with a 15 per cent allowance for transmission losses between the generating station and the home, the heat pump will deliver at the 52 degrees Fahrenheit outdoor condition 116 per cent of the heat that was in the fuel burned at the generating station for supplying energy to the heat pump. Under favorable conditions the heat pump can pick up from its outdoor air more than all of the losses from the system, including the heat rejected to its cooling water by the generating station. At first glance this might appear to offer encouragement to the seekers of perpetual motion machines, but a second glance reveals that, while we have increased the number of Btu available at the heat-pump condenser over what we started with in the fuel, its temperature level would not be attractive to the central-station operator as a source of mechanical work. The heat pump effects a favorable exchange of high-grade electric energy for a greater quantity of low-grade heat energy, and it is well known that the same favorable rate of exchange cannot be obtained in the opposite direction. However, the heat output of the heat pump is quite suitable for heating homes, and even at a three to one season-average coefficient of performance and 15 per cent electrical transmission losses, it gives 87 per cent over-all fuel economy. This is substantially better than can be obtained with the best domestic automatic fuel-burning equipment, and more than 50 per cent better than a good hand-fired domestic coal furnace will give. As time goes on undoubtedly more efficient central stations and more efficient heat-pump equipment will be developed, and it is not impossible to imagine that heat pumps may some day be required just from the point of view of conservation of our national fuel resources. Curve *A* in Figure 2 shows plainly that the develop-

ment of this type of system is not limited to 100 per cent fuel economy.

Of course, fuel utilization efficiency is not so interesting to the operator of a heat pump as is the annual operating cost in dollars. Here there can be a considerable variation of opinion, because there are no reliable statistics available on the actual average operating efficiencies of the various kinds of fuel-burning domestic heating plants. If we assume hand-fired coal furnaces at 55 per cent efficiency, and oil and gas automatic furnaces at 75 per cent efficiency, they would compare as follows with a heat pump averaging 3.0 coefficient of performance and using power at one cent per kilowatt hour. The heat pump would have the same operating cost as:

1. Coal at $14 per ton.
2. Oil at ten cents per gallon.
3. Manufactured gas at 40 cents per thousand cubic feet.
4. Natural gas at 80 cents per thousand cubic feet.

This is approximately the picture as it exists today for a heat pump constructed with general-purpose refrigeration equipment in a climate such as Pittsburgh and drawing its evaporator heat from the outdoor air. It can be improved substantially by circulating more house air at a lower temperature and using larger heat-transfer surfaces, thus increasing the first cost and departing from present limits of practice in year-round air-conditioning systems. It can be improved, also, by further development of the equipment, or by finding a higher-temperature source of heat for the evaporator than outdoor air.

The possibilities of higher-temperature heat sources have been well explored but possibly not exhausted. Most city water supplies are at a high enough temperature in winter to be usable as a heat source, but the cost of the water usually will exceed the power saving. The use of the heat of fusion of water by freezing ice presents the problem of disposing of tons of ice per day per home in very cold weather. The use of well water, where available for the cost of pumping, can give average coefficients of performance of higher than four to one, and has been used very successfully, but since the availability in the United States is very limited, this furnishes only a local solution to the problem.

Output Characteristics

Curve *A* in Figure 3 shows the output characteristic, calculated from test data, of a heat pump using a constant-speed 7½-horsepower condensing unit with an outdoor air evaporator. In spite of the fact that the coefficient of performance or efficiency falls off at low outdoor temperatures, the power input, as shown in curve *B*, also falls off because of the decrease in circulation of refrigerant at low suction densities as the evaporator temperature and pressure fall. Curve *C* shows the requirements of a house needing 85,000 Btu per hour at zero degrees Fahrenheit outdoor temperature, which would be a three-bedroom house of average proportions, well insulated, in a climate such as Pittsburgh or Philadelphia. Such a house would be in the $8,000 to $10,000

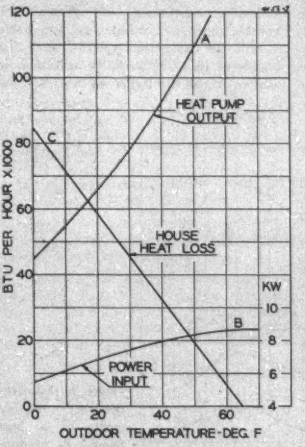

Figure 3. Output characteristics of a heat pump with constant-speed 7½-horsepower compressor

price range at prewar levels. The 7½-horsepower heat pump has capacity to heat this house down to 15 degrees Fahrenheit outdoor temperature. Rather than use a larger heat-pump system to take care of temperatures below 15 degrees Fahrenheit, a storage scheme could be used. The excess capacity of the system at temperatures above 15 degrees Fahrenheit would be used to heat water in a storage tank to a temperature of 100 to 110 degrees Fahrenheit, and when the outdoor temperature falls below 15 degrees Fahrenheit this reservoir of heat can be drawn upon to maintain the house. The size of storage tank that will be required will depend upon the severity of the longest cold spell below 15 degrees Fahrenheit to be expected at the location of the heat pump. In Pittsburgh, the size of the tank would be of the same order of magnitude as the fuel-oil storage tank that might be used if the same house were heated with an oil-burning furnace.

Sources of auxiliary heat other than storage also can be used where advantageous. The city water-supply system is a convenient source in this case, because the total usage will be small enough so that the cost is not important, and the demand would come at a season when practically all city water systems have ample surplus capacity. A small auxiliary evaporator cooling this water would be called upon for less than three per cent of the integrated heating-season demand in the Pittsburgh climate.

From curves *A* and *C* in Figure 3 it is obvious that the constant-speed compressor gives far too much capacity at the higher outdoor temperatures. This is not desirable in any warm-air heating system, where it is likely to cause short cycling and excessive temperature fluctuation in the house. This type of system, therefore, requires a multispeed compressor motor or other means of capacity reduction, with the necessary controls to modulate the system output to the approximate requirements of the house.

A requirement of 85,000 Btu per hour to heat a house at zero degrees Fahrenheit is composed of conduction through walls and windows, and infiltration of outside air. In summer the indoor–outdoor design difference is typically only 16 degrees Fahrenheit, which reduces the Btu load to 19,400 Btu per hour. To this must be added the requirements for increased fresh-air supply, people, lights, solar radiation, and latent cooling of the fresh air and people. All of these can vary widely, but it can be said that the majority of insulated houses of this size can be air conditioned satisfactorily with a three-horsepower system giving from 35,000 to 40,000 Btu per hour under hot-weather conditions. Some houses with large glass areas exposed to the sun may require five-horsepower systems. This is typical of most parts of this country, and brings out the fact that few summer air-conditioning systems, designed as such for residential use, can be converted to heat pumps without adding capacity. Conversely, the cost of installing a heat pump in a residence involves more than just the extra cost of controls and reversing mechanism applied to a summer air-conditioning system. Whereas the capacity of the condensing unit may have to be increased in the ratio of 7½ horsepower to three horsepower, the increase in size of heat transfer and air-handling equipment generally will be considerably less.

Initial Cost

Any authoritative discussion of installed prices of heat pumps would be hopelessly beyond the scope of a short exposition such as this. It would involve the effects of local codes and building-trades practices, methods of selling and installing, selection of installation materials, and all the other things that cause large variations in prices between one locality and another, and between two installations in the same locality when the system is assembled from individual pieces specifically engineered in the field

to the requirements of a particular house. Nonetheless, some highly approximate estimated figures might be of value as an indication of relative costs compared to those of conventional systems. A warm-air oil-fired furnace for a new well-insulated house requiring 85,000 Btu per hour might be sold for $700 today in a medium-size city. This would include uninsulated duct work, grills, oil tanks, and all necessary items for a complete installation, with a minimum of accessories. If this installation had been purchased as a year-round system, the duct sizes would have been somewhat larger, parts of the duct work would have been insulated, and the added equipment might have included a three-horsepower condensing unit, an evaporator coil mounted in the supply-duct work, an evaporative condenser, refrigerant piping, cooling controls, refrigerant, and numerous smaller items. If the same method of estimating is used as in the case of the simple furnace, this system complete would be sold for $1,650. Again, if the same basis for estimating is used, a 7½-horsepower heat pump with two-step capacity modulation, outdoor-air evaporator supplemented with a 1,000-gallon insulated water-storage tank for peak load, and automatic controls except for manual changeover from heating to cooling, would be sold for $2,600. The heat pump might in some cases be entitled to a credit of approximately $150 because it would not need a chimney. These figures are not represented as being either average or typical, but are prices that might be encountered in a climate such as Pittsburgh if the standard heating and refrigeration equipment available today were used. The cooling equipment would be selected and installed by the contractor in the field from various designs and sizes of compressors, fans, heat-transfer surfaces, and so forth. Obviously, whenever a volume is reached sufficient to justify pre-engineered packaged designs assembled in factories, the price of the complete system to the user would be considerably altered.

Energy Usage

Figure 4 shows the effect on electrical demand of installation of various types of systems in the typical six-room house in a Pittsburgh climate. Curve *A* is for reference, and shows the average hourly demand of an all-electric home, containing all electrical appliances except heating and air conditioning. It averages 360 kilowatt-hours per month total usage, and it will be recognized readily that few homes of this size actually approach or seldom exceed this figure. Curve *B* shows the demand of a three-horsepower summer air-conditioning installation in the same house on a hot day, when the outdoor temperature reaches 96 degrees Fahrenheit in the afternoon. Curves *C* and *D* show hourly demand curves for a heat pump in this house on a mild day and on a zero degree Fahrenheit day, respectively. If this house were heated with electric resistance heaters, the peak demand of the heating system would be 25 kw.

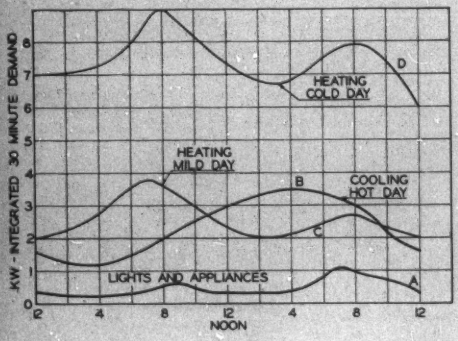

Figure 4. Kilowatt-demand requirements of a heat pump at various conditions

Estimating the average annual energy consumption of a heat pump is obviously a tedious undertaking, because the coefficient of performance is a function of outdoor temperature and the result is doubly dependent on the weather. However, approximate calculations for the average Pittsburgh climate, including both winter heating and summer cooling, give a total usage of 17,000 kilowatt-hours per year. If Pittsburgh represents an average climate in the United States, for which reason it was chosen here, then, even after all homes have reached a lighting and appliance usage of 4,000 kilowatt-hours per year, it would require installation of heat pumps in only 25 per cent of them to double the domestic electric load.

Conclusions

Quite apart from the residential possibilities of heat pumps, these systems should receive greatly increased attention in the postwar period because of their commercial and industrial applications. Many industrial applications will be found where there will be an economically advantageous use for both the heating and cooling that these systems provide simultaneously. Many industrial and commercial applications will be found where summer air conditioning is necessary, and where a high internal cooling load will make the cooling equipment adequate as a heat pump without increasing its size. Again, the availability of well water or process waste heat at a temperature too low for space heating but above outdoor temperature may make the heat pump, as an addition to a cooling system, far more attractive economically than in the case of the residential application.

If the increased interest is to carry over into the residential field and result in any widespread use, it is clear that further development work will have to be done. At present costs and performance it can be predicted safely that usage will be very limited except possibly in southern California and Florida, where the climate is much more favorable than in Pittsburgh. However, from the standpoint of first cost, it is also clear that the heat pump, when developed, will be attractive principally to those people who want and can afford to pay for over-all summer air conditioning of their homes and not for just one or two rooms. To date this market might be described as extremely small but promising. Equipment consisting of an electrically driven summer air-conditioning plant in combination with a fuel-burning furnace has reached a good stage of development, and application of it to residences is well past the pioneer stage. However, it has not received the promotion that manufacturers and utilities gave to the household electric refrigerator, for example, when it was introduced. Certainly endeavors will be made to promote it in the postwar period. The future development of the heat pump for residential use probably will depend upon the relative success or failure of these endeavors.

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Modern Cargo-Winch Control for Use on Victory Ships

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THE electric-driven cargo winches used to load and unload a modern cargo vessel are required to give fast efficient operation. Wartime conditions have made the time for loading and unloading cargo more important than ever. In addition to the need for optimum operating characteristics, the war has also brought about changes in the construction and assembly of the winches and their associated control. Every square foot of deck space is needed to carry cargo to the fighting fronts, and the space allotted to the winch must be kept to a minimum. In the past the winch, the control panel, and the resistor had been furnished separately, then mounted and wired on the ship. The time to install all this equipment on the vessel is now too long to keep pace with the accelerated shipbuilding program. The problem is being solved by furnishing the winch, the control, and the resistor, as a unit. This unit is interconnected so that very little wiring must be done on the ship and the installation time is materially reduced (see Figure 1).

In this paper the operating characteristics required for an electric-driven cargo winch will be discussed. The manner in which these characteristics may be obtained by the use of a properly designed motor control, and the problems encountered in incorporating control equipment in an enclosure mounted on the winch will be outlined.

Control Requirements for the Cargo Winch

Most cargo is handled by using two winches operating on a burtoning rig (see Figure 12 and appendix). This setup results in one winch hoisting the load and transferring the load to the other winch which lowers it. Either winch will hoist a load of a ton and a half at a speed of 290 feet per minute. Desirable operating characteristics for these winches are:

1. Speed characteristics suitable for use on a burtoning rig. The speed of one winch at light load must be matched by the other winch operating at full load.
2. Rapid acceleration and deceleration of the load to decrease the load travel time. Acceleration of the load is an important factor in placing the load under the hatch.
3. Extremely low speed, from 10 to 20 feet per minute, lowering to land heavy loads. This feature is important when lowering a load into a lighter. The lighter may be moving up to meet the load, by the action of a wave, which effectively increases the landing speed.
4. High hoisting and lowering speeds with an empty hook, approximately 400 feet per minute to give fast loading cycle.
5. Intermediate hoisting speeds at light loads are necessary to transfer the load smoothly from one winch to another. These intermediate hoist speeds also give better control of an empty hook.
6. Good jogging characteristics.

The desired cargo-winch operating characteristics may be obtained by the use of a d-c compound-wound motor. The proper connections of the motor to the line on the various operating points must be provided by the control equipment. These power-circuit connections for each point are shown, and the reasons why they are used are explained in the following.

First-Point Hoisting

This is a low torque point used to take the slack out of the cable and gears. The motor is connected to the line through a relatively large value of resistance, which limits the torque that may be produced on this point. In order to reduce the light-line speed a resistance is connected directly across the motor, inside the line resistance, which limits the no-load armature voltage. The circuit is shown in Figure 2.

Figure 1. One-unit cargo winches installed on board ship

Second-Point Hoisting

A relatively low speed with full load is needed on this point. This may be obtained by using the same circuit as used on the first point and merely reducing the line resistance. This circuit gives a little greater light-line speed and produces enough torque to hoist full loads slowly. The circuit is shown in Figure 2.

Third-Point Hoisting

The load speeds must be increased on this point and there is no need to hold the light-line speed to a low value as the two intermediate speeds provided on the first two points are sufficient. The load speed can be increased by removing the motor shunt resistor which also permits the light-line speed to increase. The circuit is shown in Figure 2.

Fourth-Point Hoisting

This point gives greater hoisting speed which is obtained by cutting the value of line resistance.

Fifth-Point Hoisting

The higher speed on this point is obtained by connecting the motor directly to the line.

First-Point Lowering

Extremely low speeds with all values of load are desirable on this point properly to land heavy loads. In addition, the motor should be capable of paying out cable with no load on the hook. The low speeds may be obtained by using a compound-wound motor, as a shunt-wound machine with heavy field excitation. This is accomplished by connecting the series field to the line through a resistor and shunting the armature across the series field. If the value of line resistance is kept low enough, the motor will have sufficient breakaway torque to start a light line downward. The speed on this point is extremely low, even with the heaviest overhauling load. The circuit is shown in Figure 2.

Second-Point Lowering

The higher speed that is required on this point is obtained by weakening the

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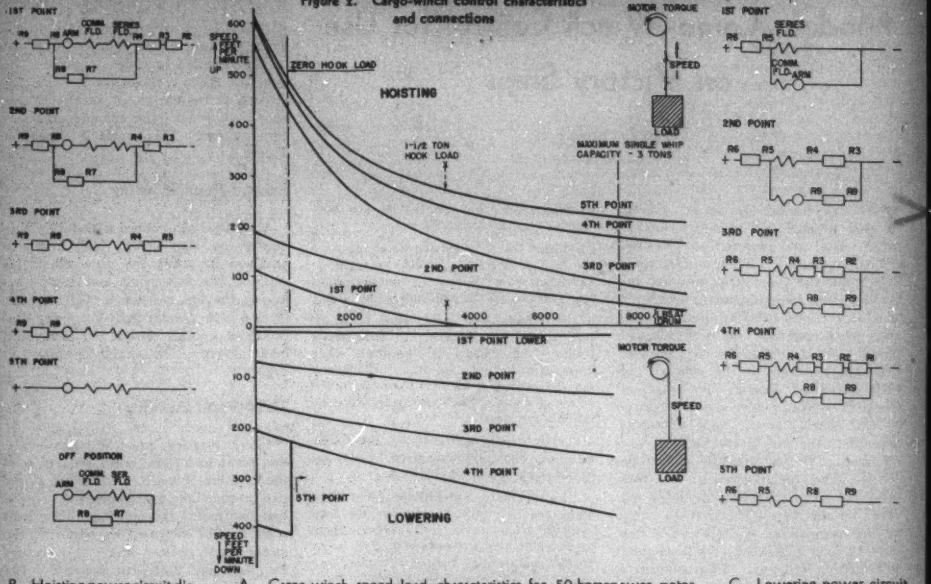
Figure 2. Cargo-winch control characteristics and connections



B. Hoisting power circuit diagrams

A. Cargo-winch speed–load characteristics for 50-horsepower motor geared to winch with 15 to 1 ratio

C. Lowering power circuit diagrams

motor-field excitation. A resistance is also inserted in the armature circuit, so there will be a little more variation in speed with load. This lines up the full-load speed on this point with the no-load speed on the third point. See Figure 2. This is important when burtoning a load, as one winch is handling full load and the other no load. The circuit is shown in Figure 2.

Third-Point Lowering

The increased speed on this point comes from a further reduction in field excitation, by the increased resistance in the series-field circuit. The rest of the circuit is the same as that on the second point. The full-load speed on this point lines up with the no-load speed on the fourth point, which is valuable for burtoning (see Appendix 1). The circuit is shown in Figure 2.

Fourth-Point Lowering

Another speed increase is obtained by a further reduction in series-field excitation. Full-load speeds on this point line up with the speed at no load on the fifth point.

Fifth-Point Lowering

A high light-line lowering speed to decrease the time to return the empty hook must be furnished on this point. This speed is obtained by reducing the field excitation to a low value.

In this case, the series field is entirely removed from the circuit, and the only field comes from the shunt field. This speed is extremely high, and it would not be safe to handle loads at this speed. For this reason, the connection is maintained only with light loads, and, if the hook is loaded, the control circuit automatically returns the motor to the fourth-point connections.

Off Position

An emergency dynamic-braking circuit, made up of the series field, the armature, and a resistor, is available in this position. This circuit automatically will provide a restraining torque for any overhauling load in case of power failure.

Description of Control-Circuit Problems

A number of interesting control-circuit problems was encountered in obtaining the desired motor power connections. Rapid response of the motor to the movement of the master-switch handle is needed to give good jogging characteristics. When the master-switch handle is moved, circuits are established to release the brake and to energize the motor. The pickup speed of the brake and the time required for the contactors to close determine the ease with which the load may be jogged. The brake pickup speed is increased by the use of a quarter-voltage coil on the brake, connected to the line through a resistor. This combination reduces the effective circuit inductance which cuts the time of the current buildup, and thereby increases the pickup of the brake. The contactors designed for this application pickup and drop out much faster than the ones previously used. These contactors are connected in such a manner that they pick up directly from the master switch and do not have

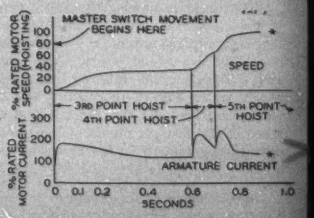


Figure 3. Acceleration curves

Hoisting from standstill to full speed with full load on the hook. Master switch thrown instantaneously from off position to fifth-point hoist

* Motor operation on fifth point is with weakened shunt field

to wait for sequencing from other devices.

Another function of the control is to make rapid acceleration of the load possible. This is important when lowering, as it permits the stevedore to swing a load under the hatch coaming by starting the load to swing and then paying out cable as it swings in the desired direction. The more rapid the acceleration, the more the advantage that may be taken of the swing to place the load in the desired position. Rapid acceleration in the hoisting as well as in the lowering direction reduces the total travel time. Very rapid load acceleration without exceeding maximum permissible torque is obtained by the proper spacing of the speed-torque characteristics in the hoisting direction, the addition of a timing relay to maintain operation on point three for a half a second, and the operation on point four for as long as it takes 3A contactor to pick up through an interlock on 2A. The current-versus-time and speed-versus-time curves for fast movement of the master switch are shown in Figure 3. Faster acceleration in the lowering directions is obtained by increasing the motor torque that drives the load downward. Gravity helps accelerate the loads in the lowering direction, and rapid release of the brake is important.

The control problem that requires more attention than all others is the establishment of a decelerating circuit that will smoothly slow down a load being lowered at high speed without causing poor commutation. The circuit must be laid out on the basis that a stevedore may be operating the winch at full load and full speed, and may then rapidly return the master switch to an intermediate or the off position. When the winch is lowering full load, the motor is acting as a generator with a very weak field and its counter electromotive force is equal to or slightly higher than line voltage. As the master switch is moved toward the off position, the resistance in the motor loop circuit is decreased and the counter electromotive

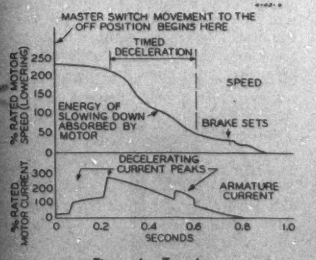
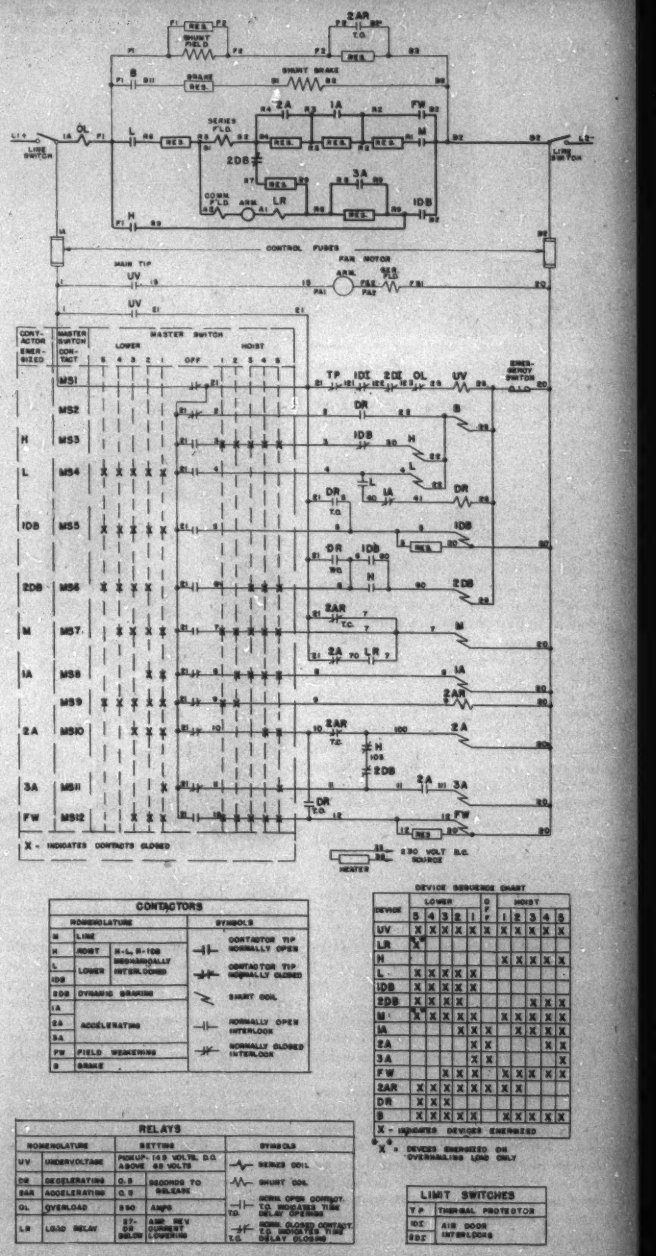


Figure 4. Test data

Deceleration from high-speed lowering with full load to standstill. Data from oscillogram taken during factory test on cargo winch



CONTACTORS

NOMENCLATURE		SYMBOLS
M	LINE	CONTACTOR TIP NORMALLY OPEN
H	HOIST H-L, H-IDB MECHANICALLY INTERLOCKED	
L	LOWER	CONTACTOR TIP NORMALLY CLOSED
IDB	DYNAMIC BRAKING	SHUNT COIL
2DB		
1A	ACCELERATING	NORMALLY OPEN INTERLOCK
2A		
3A		
FW	FIELD WEAKENING	NORMALLY CLOSED INTERLOCK
B	BRAKE	

DEVICE SEQUENCE CHART

DEVICE	LOWER 5	4	3	2	1	OFF	HOIST 1	2	3	4	5
UV	X	X	X	X	X	X	X	X	X	X	X
LR	X*										
H							X	X	X	X	X
L	X	X	X	X	X						
IDB	X	X	X	X	X						
2DB	X	X	X	X					X	X	X
M	X*	X	X	X	X		X	X	X	X	X
1A				X	X	X		X	X	X	X
2A					X	X				X	X
3A					X	X					X
FW			X	X	X		X	X	X	X	X
2AR	X	X	X	X	X	X	X	X			
DR	X	X	X								
B	X	X	X	X	X		X	X	X	X	X

X - INDICATES DEVICES ENERGIZED

X* - DEVICES ENERGIZED ON OVERHAULING LOAD ONLY

RELAYS

NOMENCLATURE		SETTING		SYMBOLS
UV	UNDERVOLTAGE	PICK-UP 165 VOLTS, D.C. ABOVE 60 VOLTS		SERIES COIL
DR	DECELERATING	0.3	SECONDS TO RELEASE	SHUNT COIL
2AR	ACCELERATING	0.3		NORM. OPEN CONTACT, T.D. INDICATES TIME DELAY OPENING
OL	OVERLOAD	550	AMPS	NORM. CLOSED CONTACT, T.D. INDICATES TIME DELAY CLOSING
LR	LOAD RELAY	27-29 BELOW	ARM. REV. CURRENT LOWERING	

LIMIT SWITCHES

TP	THERMAL PROTECTOR
IDL	AIR DOOR INTERLOCKS
2DL	

Figure 5. Elementary diagram of cargo-winch control

Figure 6. Front view of unit winch control with all doors open

series field, with a light load. The use of a normally closed interlock on $2AR$ connected to the coil of M prevents removal of the series field with a light load. The use of a normally closed interlock on $2AR$ connected to the coil of M prevents removal of the series field if $2AR$ is de-energized and the shunt field weakened. The control circuit with the safety features mentioned that gave the necessary power connection is shown in the elementary diagram (Figure 5).

Construction of Control Equipment

The specifications for cargo-winch control on the newer vessels require the control equipment with the exception of the master switch to be mounted directly

force will circulate a large current through the motor armature and series field. If the loop-circuit resistance is cut out quickly before the load is slowed down and the counter electromotive force decreased, the current values will be large, and poor commutation will result. For this reason it is necessary to sequence the action of the contactors to give a time delay in reducing the resistance in the loop circuit. It is not enough to sequence the devices; a time-delay relay must provide prolonged operation with an intermediate value of resistance. This slows down the load, thereby reducing the counter electromotive force and the resulting current peak when the loop-circuit resistance is decreased. The current-versus-time and speed-versus-time curves obtained for rapid deceleration of full load are shown in Figure 4. The automatic-deceleration feature not only makes it possible to bring the load to rest as quickly as practical, but also permits plugging from the lowering to the hoisting direction. The deceleration of the load by the motor reduces the job to be done by the brake in stopping the load. On the winch-control circuit, the release of the electric brake is held off until the timed deceleration is completed. This prevents the brake from setting until the dynamic-braking circuit has reduced the speed at which the brake would be applied to approximately one half. This reduces the wear on the linings considerably.

One other part of the winch-control circuit is the safety features provided. The use of a shunt-wound brake is necessary on this application, since the current distribution between the series field and armature circuit is not well suited for the use of a series-wound brake. The series brake usually is considered very safe, as it is located in the power circuit (between $S2$ and $R4$), and a failure in the supply sets the brake. Some of the safety features of a series brake can be obtained when using a shunt brake, if the coil of the brake contactor is connected in series through H or L coils. This prevents release of the brake if coils of either of these

Figure 7 (left). Normally open contactor

Figure 8 (right). Normally closed contactor

devices fail. The most serious failure which could occur would be that of the H contactor when hoisting, as the load starts to drop, and there is not as much tendency for the stevedore to return the handle to the off position. An emergency switch is provided for stopping the motor. The circuits are set up so that failure of H or IDB contactors de-energizes the coil of the normally closed emergency contactor $2DB$. This establishes the off-position dynamic-braking loop circuit. Another safety feature is the interlocking provided between the relay $2AR$ and contactor M. The relay $2AR$ weakens the shunt field when it is de-energized, thereby providing higher light-line speeds on the last three hoisting points. If this relay should fail to remain in the closed position in the lowering direction, the motor speed would be high. This is very important on the fifth point as the contactor M is opened, removing the

on the side of the winch. In this location the equipment must be protected from the action of rain and waves, as well as take a minimum amount of space. The standardized Maritime Commission design for control equipment has the electric brake, the control panel, and the resistor located in separate compartments of a large waterproof enclosure on the

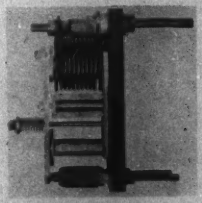


Figure 9. Load relay

side of the winch. See Figure 6. The case is constructed of 3/16-inch steel, reinforced with partitions to give it increased strength. The control panels located in the middle compartment must be easy to service and relatively easy to remove if this should be necessary. This necessitates the panel being built in three sections which may be removed from the front of the enclosure. The weight and size of each panel is kept small by the use of a new-type marine contactor. The new normally open as well as the normally closed contactors have their armatures pivoted on synthetic-rubber bearings. The normally closed contactor is provided with an Alnico magnet to give rapid opening of the main contact tip. See Figures 7 and 8. Totally enclosed electrical interlocks are used with these new contactors. The relays are located on the bottom panels, and the load relay, which gives high-speed lowering with light load, is especially designed for this application. The relay is both small and lightweight. The device has a magnetic circuit made up of an Alnico magnet and a series coil carrying motor-armature current. See Figure 9. The design of the device is such that it gives positive snap action when the critical value is reached. A heater of 100-watt capacity is located in the panel compartment to keep the temperature above the outside ambient temperature, and prevents condensation of moisture.

The magnetic brake is solenoid-operated with the solenoid located above the motor shaft. This construction keeps the width of the brake compartment small. The brake designed for this application, shown in Figure 10, is a two-shoe brake. The brake resistor also is located in the compartment.

The power resistor (see Figure 11), which is located in the remaining compartment, is called upon to dissipate quite a bit of power, particularly on the slow-speed point. It was not possible to furnish a totally enclosed resistor in the available space because of the temperature rise of the resistor and case that would result. The only alternative was to provide forced-air ventilation for the resistor. The specifications require the resistor compartment to be watertight when the equipment is not being used and the ship is at sea. The openings used for air intake and outlet for resistor ventilation are provided with watertight doors. These doors are opened when the equipment is to be operated, and interlock switches connected to the doors prevent operation of the equipment unless the doors are open. The resistor units, boxes, and interconnections are built to operate, even though rain is being driven into the air openings. The entire front of the resistor compartment may be removed, if it is necessary to replace resistor units. All of the units are mounted in unit

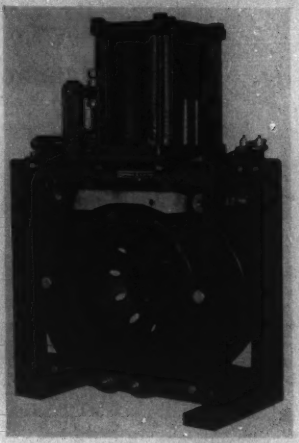


Figure 10. Magnetic brake used on unit cargo winch

boxes. There are seven of these boxes, and each box slips into its own tray and is held in place by a clip at the back and two screws at the front. The interconnections between boxes are such that they may be removed from the front and the box taken out easily. The resistor ventilation is furnished by a propeller-type fan which is capable of delivering 1,000 cubic feet of air against a static pressure of 3/8 inches of water. This fan is driven by a one-quarter-horsepower, 1,750-rpm series-wound motor. The series-wound motor being used to obtain maximum air delivery is located below the resistor. The fan actually delivers 1,500 cubic feet of air a minute, as the fan load is less than fan motor rating and the motor runs at 1,965 rpm.

It was necessary to run a series of tests to determine the manner in which the resistor should be built. The first test that was run on the resistors was to determine the amount of power that could be put in each box with different numbers of boxes carrying current. That is, the top box is capable of carrying 145 per cent of its open power rating when no other boxes are in the circuit, but when all seven boxes are in the circuit the top box can only carry 105 per cent of its open power rating without exceeding the permissible temperature rise. These data were used to determine the best location for each section of resistance in the stack of boxes. After the sections were located, it was possible to estimate the length of time each section could be left in circuit for the various master-switch positions. Data regarding the time required for resistor units of this type to reach temperature with different percentages of their rated power applied made such estimating possible. On the basis of preliminary layouts, a sample resistor was made and tested under a great variety of operating conditions which would be encountered in actual service. Data already collected from numerous shipboard tests made over a period of years served as a background for determining how long the resistor should be capable of operating on each point. Assumed duty cycles are of little value in estimating the sizes of the various resistor sections because of the abuse this type of control receives from unexperienced operators. The final design of resistor contains 35 units and has ample capacity for operation on average duty cycle for 15 minutes without forced-air ventilation. Another feature of the resistor compartment is the thermal

Figure 11. Front view of resistor compartment with door removed

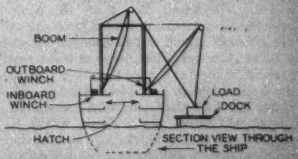


Figure 12. Sketch of bartoning method of loading and unloading a ship

switch which is employed to protect the resistor from dangerous overheating due to some unusual conditions, such as fan stoppage or blocking of the air-intake door. The fan motor is fed from the main contact tips on the control undervoltage relay and through the control fuses which should give fan operation as long as the control is energized.

The resistor is very difficult to protect, as it is essential to trip out the control for a small amount of power in the stack or from a relatively large amount of power in the same length of time. The reason for this is that the resistor is made up of six sections, used in various circuit locations, and each section has a different power rating and time on requirements. A number of different types of thermal switches was tested, and it was found that the switch had to have a best heat response to protect the edgewise resistor units which do not have a great amount of thermal capacity. The next problem was to determine the exact spot where it should be placed in order to protect as many of the sections as possible on the various operating parts. The location of the thermal switch was above the resistor stack, so that the heat representing large kilowatt dissipation low in the stack would trip the switch. The unit also would function with a relatively low kilowatt dissipation on the top units. The action in the latter case was mainly from radiation from the top units. This switch is entirely waterproof, as it is located where rain could damage it. It is not necessary to remove the thermal switch to take out resistor boxes, as it is mounted on the top of the air baffle. The thermal switch selected protected the resistor sections on most operating points as well as protecting the resistor on a normal operating cycle.

Appendix

The method of cargo handling known as burtoning consists of the use of two cables connected to the load. One cable is fed over a boom which is swung above the hatch of the vessel, while the other cable is fed over a boom above the dock. A separate cargo winch is used for each boom. Each of these winches is under the control of its own master switch. The winch that feeds cable over the boom above the dock is known as the outboard winch. The load is hoisted from the dock by the outboard winch. The winch that feeds the cable over the boom above the hatch is known as the inboard winch. The inboard winch pulls in slack cable but does not hoist any part of the load as the load is moved above the dock. As soon as the load is far enough above the dock that it may be transferred above the hatch, the inboard winch is speeded up. This pulls the load toward the hatch, and the load may be moved more by paying out cable from the outboard winch. The load may be lowered into the hatch by lowering the load on the inboard winch and paying out cable on the outboard winch at a speed slightly in excess of the inboard-winch cable. The sketch in Figure 12 indicates the relative positions of the cargo booms on the vessel. There is hardly any swinging of the load with experienced operators. This method of cargo handling permits rapid loading and unloading of a vessel.

Operation of Rectifiers Under Unbalanced Conditions

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THE development of single-anode rectifying elements has greatly stimulated the application of rectifiers to general industrial and essential duty loads. Sealed ignitron rectifiers[1] have been made available in a range of ratings, and industry is vitally interested in the performance of these equipments when operated under conditions of partial-anode complement, as when an anode is misfiring or is entirely out of service.

A multiphase mercury-arc rectifier and its associated transformer are designed, so that, under normal conditions, the current in all circuit elements will be balanced, and there will be no d-c components of flux in the transformer core. When the rectifier equipment is operated on less than normal-anode complement, the circuit is no longer symmetrical, and the remaining anodes do not share the d-c load currents equally. Under this condition, a d-c component of flux exists in the transformer core, and the interphase transformer is adversely affected by unbalanced currents in the two halves.

The purpose of this paper is to describe the distribution of currents in the various transformer windings and rectifying elements under conditions of unbalance and to indicate the effect of such unbalances on the circuit duty and the rectifier capacity.[2] The paper is concerned with the temperature rise of transformers, transformer life, and the duty on the rectifying elements arising from both the magnitude and wave shape of the anode currents. The problem is best approached from an analysis of measurements made on standard equipments.

Scope of Tests

The mercury-arc rectifier utilizes a number of rectifying elements in combination with transformers and other apparatus. The heating of most of the components is determined by rms values, and the equipment is designed to meet definite temperature rise limits. The important factor in establishing temperature limits is the thermal endurance of insulation and other materials used in construction. It is well known that the physical deterioration of insulating materials under the influence of time and temperature increases rapidly with temperature. The temperature rise, therefore, influences directly the probable life and reliability of the apparatus.[3]

The design and construction of the rectifying elements are such that time and temperature have little effect on life. The capacity of the device is limited only by the ability of the ionized vapor to conduct the current from the anode to the mercury pool and by the probability of arc-back which increases as the peak current increases. The usual design of the rectifying element is, therefore, a compromise between these factors. A design for low arc-back frequency is accomplished by baffles and shields which tend to aid the deionization properties at the expense of arc-drop and a decrease in the peak ampere capacity. These factors are not directly determined by temperature rise, since the capacity of the rectifying element is influenced by the characteristics of the circuit. The accelerated-load test, or "load-limit test,"[4] is used primarily to determine the capacity of the rectifying element.

In order to determine the d-c load current which can be carried when operating on less than normal-anode complement without undue heating of any part of the rectifier transformer, or exceeding the maximum loading at which the rectifying element is capable of operating without failure, it is necessary to know the distribution and wave shapes of current in the primary, secondary, and interphase windings. The procedure used in obtaining data of this nature is to make temperature measurements and to study wave shapes of currents with typical circuit arrangements, so that the analysis of

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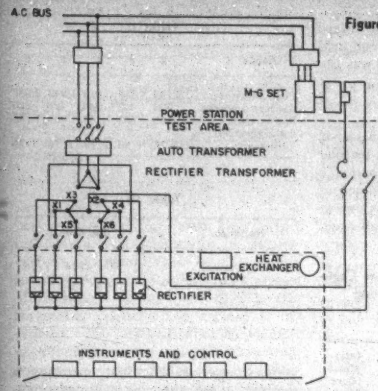


Figure 1 (left). Arrangement of test equipment

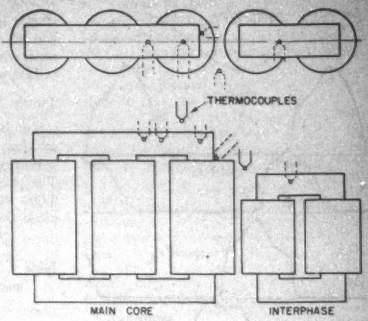


Figure 2 (right). Thermocouple locations

Double-wye transformer

data obtained in a few specific cases will enable the design engineer to predict the performance for a range of ratings.

A typical circuit diagram of equipment for determining rectifier-circuit duty operating with less than normal-anode complement is shown in Figure 1. Shunts and ammeters connected in the anode leads permit the reading of the average anode-current distribution. A multi-element oscillograph is used to obtain the wave shapes of all anode and transformer primary currents.

For most applications, circuits which utilize simple rectifiers operating in parallel are preferable. In such circuits the total load is divided equally between the simple rectifiers. Arc losses are a minimum, and the current capacity of the equipment is a maximum. Tests, therefore, were conducted on equipments with double-wye transformers rated 150 kw and 1,000 kw at 250 volts direct current. Tests also were made on a 200-kw 275-volt d-c double-biphase transformer. Test results on the 150-kw and 1,000-kw equipment were very similar; hence, discussion is limited to the 1,000-kw unit.

To determine the transformer heating, readings of the top oil, ambient, and core temperatures were taken under various conditions of loading. For core-temperature measurements, thermocouples were placed in the main and interphase core during assembly with leads brought out through a manhole opening in the cover. The location of the thermocouples for the double-wye transformer is shown in Figure 2. Because of the difficulty in locating the thermocouples on the hottest surface, which is the underside of the top yoke, they were placed between laminations near the top and measurements corrected for the hottest surface temperature.

To determine the duty on the rectifying elements, as well as to evaluate factors affecting the permissible transformer load, an analysis was made of the primary line current, anode currents, and voltage oscillograms.

Test Procedure

Normal Operation

To provide a basis of comparison, a normal heat run was made on a rectifier equipment with all anodes conducting. The rectifier transformer was rated 1,190 kva and 6,600/243 *L-N* volts with a double-wye secondary winding designed for a 1,000-kw 250-volt 6-anode ignitron rectifier. The primary voltage was maintained at 6,600 volts, 60 cycles, and the load was adjusted to a 4,000-ampere d-c output, at zero phase retard, and continued until constant oil temperature rise was obtained.

Since the a-c voltage across the interphase transformer and, consequently, its core losses increase with the amount of phase retard, the run was continued with 15 per cent phase retard, until constant interphase core rise over oil was reached. Oscillograms were taken of the primary

Figure 3. Core and top-oil temperature rise

1,000-kw double-wye transformer, five-anode operation

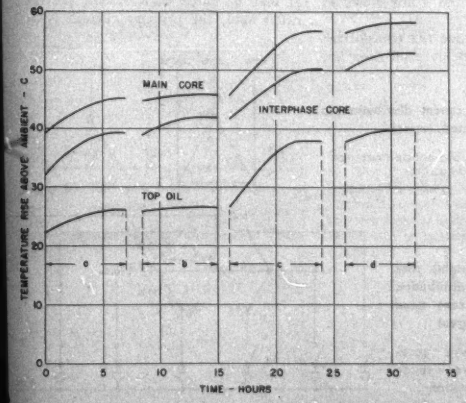
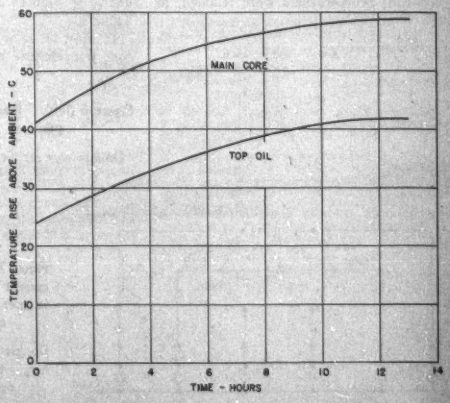


Figure 4. Core and top-oil temperature rise

1,000-kw double-wye transformer, three-anode operation



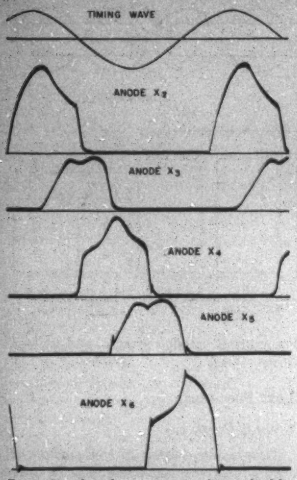


Figure 5. Anode-current wave forms, double-wye rectifier, anode X_1 inactive

voltage, primary and secondary currents in all phases.

Five-Anode Operation

Temperature measurements were made on the rectifier transformer operating on five anodes with anode X_1 disconnected. The primary voltage was maintained at 6,600 volts, 60 cycles. The load was reduced to 2,300 amperes d-c output at zero phase retard and held until constant main and interphase core rise over oil was reached, as shown in Figure 3*a*. The phase retard then was adjusted to 15 per cent, and the run continued, as shown in Figure 3*b*.

The load was increased then to five sixths of full-load rating or 3,333 amperes at zero phase retard and maintained until constant temperatures were reached, as shown in Figure 3*c*. The phase retard was set at 15 per cent, and the load held until constant core rise over oil was obtained, as indicated in Figure 3*d*.

Three-Anode Operation

To obtain data with one wye inactive, another run was made with the rectifier operating on anodes X_2, X_4, and X_6. The primary voltage was maintained at 6,600 volts, 60 cycles. It was recognized that more than one-half load could be carried with one wye operating; therefore, two-thirds rated load or 2,670 amperes d-c output at 15 per cent phase retard was held until constant oil rise was obtained. The results of the test are shown in Figure 4 and Table I.

Table I. Temperature Rise—Degrees Centigrade at 15 Per Cent Phase Retard

Double-Wye Transformer

Per Cent Load	Number of Anodes	Top Oil Above Ambient Temperature	Main Core Above Oil	Interphase Core Above Oil
100	6	41.5	17.5	17
57.7	5	26.5	19.0	15
83.3	5	40.0	18.0	13
66.7	3	42.0	17.5	0

Double-Biphase Rectifier

Similar measurements were made on a 200-kw 275-volt double-biphase rectifier. A heat run was made operating with all anodes conducting at 15 per cent phase retard and 100 per cent load current. The test was continued when operating with three anodes at 15 per cent phase retard and 75 per cent load current.

Analysis of Data

Temperature Measurements

A summary of temperature measurements of Figures 3 and 4 are shown in Table I.

It may be seen that the transformer core temperature rise over oil does not increase appreciably when operating a rectifier on less than normal-anode complement, and that, under any of these test conditions, the hottest core surface rise above ambient temperature did not reach the permissible limit of 65 degrees centigrade. The core temperature, therefore, is not a determining factor in limiting the load which can be carried under this condition of operation.

Table II

Anode	2	3	4	5	6
Peak amperes	3,159	1,810	2,610	1,948	3,087
Average amperes	831	427	644	526	832
Rms amperes	1,466	789	1,138	926	1,462
Ratio effective/average	1.76	1.85	1.77	1.76	1.76

Table III

Harmonic	Per Cent I_L
Fundamental	89.0
2	45.0
3	
4	6.3
5	6.8

Table II shows the data obtained when an analysis is made on a typical oscillogram of anode current, as shown in Figure 5.

The rms current distribution in per cent of rated current in the various transformer windings of a double-wye rectifier with one anode inactive and with zero phase retard is shown in Figure 6. It may be noted that the output of the rectifier will have to be reduced approximately to 60 per cent of rated d-c current in order not to exceed the normal current rating of any winding. Under emergency conditions, however, it may be necessary to overload and, consequently, decrease the transformer life expectancy.[3]

The current distribution for a double-wye rectifier operating with three anodes in one wye inactive is shown in Figure 7. It may be noted that, at 66.7 per cent rated load, the primary current is 102

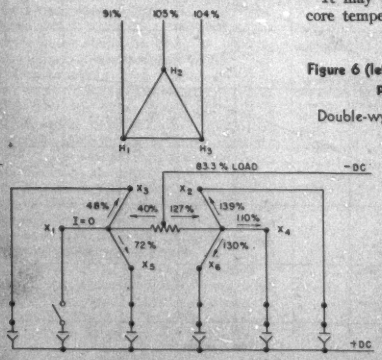


Figure 6 (left). Rms current distribution in per cent rated current

Double-wye rectifier, five-anode operation

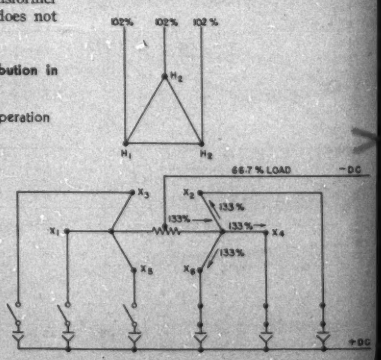


Figure 7 (right). Rms current distribution in per cent rated current

Double-wye rectifier, three-anode operation

Table IV. Temperature Rise—Degrees Centigrade

Per Cent Load	Number of Anodes	Oil Above Ambient Temperature	Main Core Above Oil	Teaser Core Above Oil	Interphase Core Above Oil
100	4	28	4	4	8
75	3	31	7	7	11

per cent of normal rated load which indicates a large component of exciting current and considerable d-c flux in the transformer core. Another disadvantage of operating with one wye is that the distortion of primary line current is increased. The analysis of an oscillogram of primary line current gives the harmonic components in per cent of the total effective current, as shown in Table III.

The temperature rises obtained when one anode is inactive in a double-biphase rectifier operating at 15 per cent retard are summarized in Table IV.

The rms current distribution in the various elements for 75 per cent rated load current is shown in Figure 8. The output will have to be reduced approximately to 50 per cent of full load in order not to exceed the rated current of any transformer winding.

Duty on Rectifying Elements

The duty on the rectifying elements when operating on less than normal-anode complement arises from both the magnitude and the shape of the current and voltage waves. Since the instantaneous arc-drop is a function of the instantaneous current, the peak current is an important factor in determining the duty on the rectifying element. On the other hand, the residual ionization is a function of the peak current which has passed during conduction and, therefore, influences the probability of arc-back. The ratio of peak current to load current in the anode following an inactive anode in a double-wye rectifier increases from 0.5 for normal operation to 1.0 under operation with one anode inactive. A similar increase is noted for the anode preceding an inactive anode.

The final commutation rate provides a further measure of the duty on the rectifying element. The residual ionization present at the beginning of the inverse period depends on the rate of reduction of current during the last few degrees of conduction. Kingdon and Lawton[5] have indicated that the frequency of arc-back is a function of the product of initial inverse voltage by the final commutation rate. Both of these factors are increased when one anode in a rectifier is inactive; however, if the loading is reduced to come within the current limitations of the transformer windings, the frequency of arc-back is not increased. Figure 9 shows load-limit tests on a double-wye rectifier operating with normal-anode complement compared with five-anode operation. The five-anode load limits are roughly 70 per cent of the limits with all anodes active.

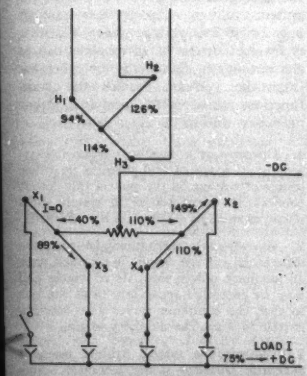


Figure 8. Rms current distribution in per cent rated current

Double-biphase rectifier, three-anode operation

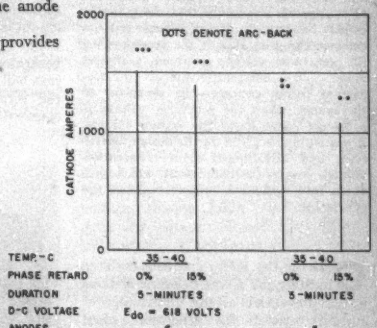


Figure 9. Load-limit tests

Double-wye rectifier, normal- and partial-anode complement

Conclusions

1. The transformer core temperature increases somewhat when operating a rectifier on less than normal-anode complement, but it is not a factor limiting the amount of load which can be carried under this operating condition.

2. Because of the large unbalances in rms coil currents with one anode inactive, it will be necessary to reduce the load to considerably less than five-sixths load for the double-wye connection and three-fourths load for the double-biphase connection. The tests indicate that the load will need to be reduced to 60 per cent for the double-wye connection and to 50 per cent for the double-biphase circuit, if the current rating of any transformer winding is not to be exceeded.

3. A very large exciting current is present when a double-wye transformer is operated with only one wye carrying load, indicating the presence of considerable d-c flux in the core.

4. If the anode of a double-wye rectifier is inactive, more load usually can be carried on the remaining five anodes than can be carried using one secondary wye.

5. If one anode of a double-biphase-connected rectifier is inactive, as much load can be carried on two anodes operating single biphase as can be carried on the three remaining anodes.

6. When the loading is reduced, because of the current limitations imposed by the transformer windings, the arc-back frequency is not increased when operating a double-wye rectifier on less than normal-anode complement.

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An Aircraft Differential-Voltage Cutout

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ASSOCIATE AIEE

Synopsis: Experience obtained with present multiengine aircraft electrical systems indicates a need for preventing interchange of current between generators when the system is operating at light loads. Such current interchange causes reverse-current cutouts of conventional design to connect and disconnect their respective generators to the system so rapidly that the action is called "chatter." Conventional cutouts connect the generator to the system when the generator voltage is above a pre-set value. The differential-voltage reverse-current cutout connects the generator to the system when the generator voltage is a pre-set value above the system voltage. A description is given on the design, operation, and advantages of a differential-voltage reverse-current cutout which prevents interchange of current between the generators.

ONE of the major problems on large multiengine aircraft electric systems is the prevention of the interchange of current between the generators when the system is operating at light loads. Parallel operation of the generators is accomplished with a circuit using equalizer windings on the voltage regulators. The effectiveness of this circuit is proportional to the difference in load current of the generators. This means that there is no paralleling action at no load and very little paralleling action at light load, which is the normal condition on an airplane. Loads nearing the capacity of the system may be encountered for only a few minutes on each flight. Voltage regulators have an accuracy of plus or minus two per cent over the entire range of ambient temperatures and generator speeds. The nominal setting for voltage regulators is now 28 volts. The specified tolerance allows the voltage regulators to regulate the generator voltage at any point between 27.5 volts and 28.5 volts. This small variation in voltage causes reverse current to flow to one or more generators. Reverse current flowing to a generator causes the reverse-current cutout to disconnect the generator from the system. However, the generator voltage may be above the pickup setting of the cutout so that it will reconnect the generator to the system.

Consider the case of an aircraft electrical system containing two generators operating in parallel under the control of two voltage regulators and two conventional cutouts.[1,2] The voltage regulator of the first generator is set at 28.5 volts and its cutout is set to connect the generator to the system at 26.5 volts. The voltage regulator of the second generator is set at 27.5 volts and its cutout is also set to connect the generator to the system at 26.5 volts. With both generators connected to the system, current will flow from the first generator to the second generator. This condition causes the cutout of the second generator

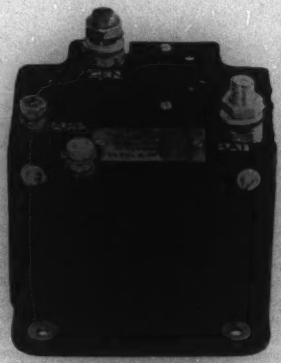

Figure 1. A 200-ampere differential-voltage cutout

to disconnect it from the system. With the cutout of the second generator opened by reverse current, the voltage on its operating coil is 27.5 volts; which is one volt higher than its operating voltage. Therefore, the cutout of the second generator will reconnect the generator to the system and the action just explained repeats. Due to the rapidity of this action, it is called "chatter." When this condition occurs the respective cutouts are continually operating, shortening their life in some instances to relatively few hours.

From this description it is evident that there is a need for a method of preventing interchange of current between generators when the system is operating at light loads.

The simplest means of eliminating the cutout "chatter" is to change the principle of operation from a device which measures the generator voltage (automotive type) to a device which measures the difference between the generator voltage and the system voltage. Hence, this new cutout is called a differential-voltage cutout. The differential-voltage cutout operates when the generator voltage exceeds the system voltage by a predetermined difference voltage. The system voltage may vary over a wide range without "chatter" of the differential-voltage cutout. In electrical systems using the differential-voltage cutout a generator cannot be connected to the system until the system voltage decreases to a point where the generator has sufficient voltage to supply part of the load.

Description

Figure 1 shows a differential-voltage reverse-current cutout designed for use with any d-c generator having a normal regulated voltage of 28.5 volts and a current rating up to 200 amperes. The device occupies a four-inch cube and weighs two pounds six ounces. Four mounting holes on three-inch centers are provided in lugs extending from the cover. All terminals extend from the top so that cables may be attached from any direction. The unit is entirely enclosed for operation in atmospheres of the severest dust and moisture content. Its operation shows negligible change when vibrated at frequencies up to 55 cycles per second with a total excursion of $\frac{1}{16}$ inch.

The differential-voltage cutout connects the generator to the system when the generator voltage is 0.4 volt above system voltage. The system voltage may be at any voltage above 20 volts. A reverse current of 16 amperes causes the cutout to disconnect its generator from the system. Besides the main function, the cutout performs other necessary duties:

1. Operates on a dead bus—when a generator is up to speed and there is no other source of voltage on the system this cutout connects the generator to the system when a load as small as eight watts is connected.

2. Operates as a starting switch—when the differential-voltage cutout is installed with an auxiliary power plant its contactor coil may be energized separately from the bus so that the contactor serves as a starting switch to start the auxiliary engine.

3. Protects the system against reversed generator polarity—if the generator builds up with reversed polarity, it is possible to have 60 volts across the differential circuit of the cutout. Under this condition the cutout does not operate nor is the differential circuit damaged even though its operating voltage is only 0.67 per cent of this value.

4. Protects the system against short circuits—should a generator suddenly lose its field or become short-circuited, a heavy surge of reverse current will flow through it.[3] The cutout must be capable of opening

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this current without damage to the cutout or further damage to the generator. The contactor of this cutout has interrupted 3,500 amperes at 50,000 feet altitude.

Design

A differential-voltage cutout presents several design problems not encountered with the conventional cutout. The primary considerations are protecting the differential-voltage winding against overheating and interrupting the differential-voltage winding to prevent discharging the battery when the generator is idle.

Because the differential-voltage winding must have sufficient excitation to operate on an extremely low voltage, it is impractical to make it withstand full system voltage (for the case of a dead generator) or double system voltage (for the case of a reversed generator) without overheating. The winding is protected by connecting a relay across the differential circuit which operates at a low enough voltage to protect the differential-voltage winding by inserting a resistor in the circuit.

On the conventional cutout the operating coil is connected to the generator side of the contactor so that the coils are not energized when the generator is idle. The nature of the differential-voltage cutout makes it necessary to interrupt the differential-voltage circuit, in addition to the main circuit, to prevent discharging the battery when the generator is idle.

Two main units comprise the cutout illustrated by Figures 1 and 2: a polarized differential-voltage reverse-current relay, distinguished by the square coil, and a magnetic contactor. Two auxiliary relays control the differential-voltage winding on the reverse-current relay. Figure 3 is a schematic diagram of the cutout.

The square spool of the reverse-current relay coil contains three windings. An inner differential-voltage winding *RCD* is connected between the generator positive terminal and the battery positive terminal through the contacts of the two auxiliary relays. A holding winding *RCH*, in series with a 470-ohm resistor, is connected between the reverse-current relay contacts and ground. An outer series winding *RCS*, consisting of a single turn of copper strap, is connected between the generator positive terminal and the generator side of the contactor. The differential-voltage winding operates the reverse-current relay contacts *RC*. The holding winding produces the magnetic force to hold the reverse-current relay contacts *RC* closed when the differential-voltage winding is short-circuited by the contactor contacts *C*. The series winding adds magnetically to the differential-voltage and holding windings when the generator is supplying current to the system. Polarization is accomplished with a permanent magnet. The design of this relay produces a strong opening force on the relay armature when a heavy surge of reverse current, such as can be caused by a short-circuited generator or the loss of a generator field, flows through the series winding. As the reverse current increases, the relay opening force increases.[1] It is impossible for this type of relay to "lock in" on a heavy reverse current.

On other types of reverse-current relays it is possible for a heavy surge of reverse current in the series winding to reverse completely the polarity of the magnetic circuit. When this condition occurs, the relay holds its contacts closed and the heavy reverse current continues to flow, causing additional damage to the system.

A special design is used on the operating magnet of the contactor. Magnetically it operates as a solenoid magnet in

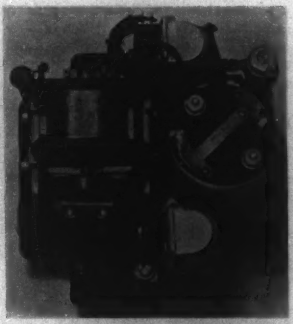

Figure 2. A 200-ampere differential-voltage cutout with cover removed

the open position and as a lifting magnet in the closed position. This arrangement uses advantages of each type of magnet and produces a contactor of minimum weight for the forces obtained. The contactor coil is composed of a main winding *CM*, and a holding winding *CH*. The main winding has low resistance and is used to operate the contactor. When the reverse-current relay contacts *RC* close, full generator voltage is impressed across this winding. As the contactor contacts *C* close an electrical interlock opens, making the holding winding *CH* in series with the main winding. The contact force obtained with this contactor is 4.5 pounds per contact, producing a voltage drop across the cutout of only 60 millivolts at 200 amperes.

Both auxiliary relays have two contacts in parallel for added reliability in completing the low differential-voltage circuit. Relay *A1* is normally open and is in series with a rectifier. It is used to complete the differential-voltage circuit when the generator voltage is over 20 volts. The rectifier is used as a d-c valve and prevents the closing of relay *A1*, if the generator builds up with reversed polarity. Relay *A2* is normally closed and is connected across the differential-voltage winding. It protects the differential-voltage winding against over voltage. When the voltage on the differential-voltage winding exceeds four volts a resistance of 80 ohms is inserted in the circuit.

Operation

With switch *S* in the number 1 position the differential-voltage cutout is ready for operation. When the generator speed is increased until its terminal voltage is 20 volts, relay *A1* will operate and complete the differential-voltage circuit. With a battery voltage of 25 volts there is 5 volts across the differential winding. Since this voltage is also applied to the coil of *A2*, the latter operates and inserts the resistor in series with the differential-voltage winding *RCD*. Increasing the generator voltage decreases the differential voltage. When the generator voltage is equal to the battery voltage there is no voltage on the coil of relay *A2*. Therefore, *A2* releases and closes its contacts, causing the resistor to be short-circuited. Now the circuit has only the low resistance differential-voltage winding to limit the current in the differential-voltage circuit. Increasing the generator voltage to 0.4 volt above the battery voltage causes contacts *RC* to close, energizing the contactor coil *CM* and the reverse-current relay coil *RCH*. The contactor coil closes contacts *C* which connects the generator to the load bus. The differential-voltage cutout is now in the normal operating position. Decreasing the generator voltage below the battery voltage causes reverse current to flow from the battery to the generator. With current flowing in the reverse direction, relay coil *RCS* magnetically opposes relay coil *RCH*. Increasing the reverse current to 16 amperes causes the reverse-current relay to open the contactor coil circuit and disconnect the generator from the load bus.

If the generator builds up with reversed

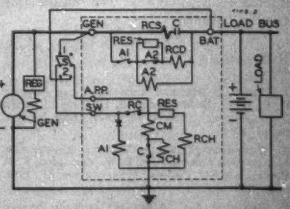

Figure 3. Schematic diagram of the differential-voltage cutout

polarity the rectifier will block the current and prevent the closing of relay $A1$.

To use the contactor of the differential-voltage cutout as a starting switch for starting an auxiliary engine, place switch S in the number 2 position during the starting period.

Advantages

Two fundamental improvements are obtained in the operation of aircraft electrical systems by using the differential-voltage cutout in place of the conventional cutout:

1. Cutout "chatter," which occurs with conventional cutouts when the system is operating at light loads, is eliminated.

2. The generator may be connected to the system at any voltage above 20 volts. This is particularly important on long flights where the generator speed is below the speed necessary to produce normal voltage. With this condition the battery supplies all of the load current until its voltage drops below the generator voltage. At this point the generator is connected to the system, preventing complete discharge of the battery.

Three additional improvements are included in the differential-voltage cutout which produces greater reliability of operation than is obtained with the conventional cutout:

1. The contactor of the cutout protects the system when a short circuit occurs in the generator.

2. Operation is not impaired in atmospheres of the severest dust and moisture content.

3. Operation is not impaired by vibration conditions encountered in aircraft service.

Conclusions

It has been shown that a cutout which is designed for differential-voltage operation has all of the advantages and none of the disadvantages of the automotive type of cutout. Also, the differential-voltage cutout has several advantages not obtained by using any other principle of operation.

The outstanding success of the differential-voltage cutout is exemplified by the preparation of an Army-Navy Specification for a differential-voltage cutout intended to supersede the automotive type of cutout.

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A Unique Moving-Magnet Ratio Instrument

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Synopsis: This paper describes a unique type of moving-magnet d-c ratio instrument. An instrument designed for temperature measurement in aircraft is described in detail.

THE remote indication of oil and coolant temperatures on aircraft has been accomplished principally through the use of temperature-sensitive resistance bulbs and moving-coil ratio instruments. A survey of the requirements indicated that a moving-magnet instrument could be developed which would fulfill these requirements and have characteristics of simplicity, serviceability, ruggedness, and lightness. Such instruments, both single and dual, are illustrated in Figure 1.

Principle of Operation

In this instrument the permanent-magnet rotor position and the indication are determined by the fluxes produced by two mutually perpendicular coil groups. One coil group carries substantially constant current; the other carries current which is a function of the temperature bulb resistance.

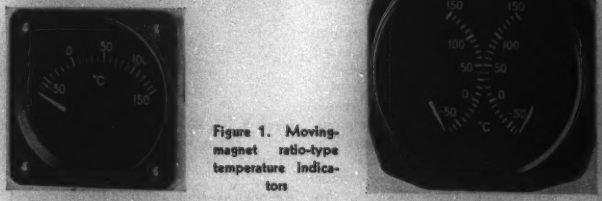

Figure 1. Moving-magnet ratio-type temperature indicators

Figure 2 shows the coils and rotor arrangement. The small outer coils serve to set up a diametrical flux along the axis of these coils. This flux corresponds to vector B in Figure 3. The current in these coils is approximately constant for all indications at any given supply voltage.

The large inner coils serve to set up a diametrical flux along the axis of these coils and perpendicular to the axis of the small outer coils. This flux corresponds to vector A in Figure 3. The current in these coils is a function of the quantity to be indicated. These coils serve as the detector in a Wheatstone bridge in which case the coil current is zero near center scale, a positive maximum at one end of the scale, and a negative maximum at the other. This is illustrated in Figure 3 where vector A is downward at −70-degrees-centigrade indication, zero at +40-degrees-centigrade indication, and upward at +150-degrees-centigrade indication. In this diagram vector C is the resultant flux. The rotor is magnetized parallel to the flat surfaces, and the rotor aligns itself with the resultant flux lines. Figure 3 is helpful for purposes of an elementary explanation of operation but does not include various distorting effects.

In the actual device the two sets of coils are surrounded by a high-permeability cylindrical shield. The purpose of this shield is to provide a return path for the internal fluxes and to screen out extraneous fields.

The Circuit

The circuit used is shown in Figure 4. Resistors R_1, R_2, and R_3 are fixed arms in a Wheatstone bridge, and R_4 is the resistance-type thermometer bulb. All resistance values are practically independent of temperature except those of the coils and bulb. Bulb-resistance characteristics are shown in Figure 5. The bridge circuit is balanced by the bulb at approximately center-scale (+40 degrees centigrade) indication and is unbalanced at all other indications. At indications below approximately 40 degrees centigrade unbalance current flows through coil A from R_3 to R_4. At indications above this value current flows through coil A in the opposite direction. Because of the values of fixed resistances in the circuit, variations in bulb

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resistance cause less than ±5 per cent variation in the outer-coil current for all scale indications at any given values of voltage and ambient temperature. For elementary considerations this current may be assumed constant.

Construction and Adjustments

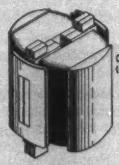
Figure 6 illustrates the construction of a single-element temperature indicator. The element is cut away showing the close magnetic coupling between the rotor and the two inner coils. These coils are wound on insulated copper-coil forms, which provide a damping structure close to the rotor to damp excessive pointer oscillations.

The permanent magnet rotor material is sintered oxide, chosen for its high coercive force and low density. The dimensions of the rotor were selected as a result of tests made to determine the optimum allocation of space to coils and rotor, for the case of a 0.7-inch-diameter enclosing shield. The rotor is mounted on an aluminum shaft provided with tantalum–tungsten pivots. The pointer is secured to the shaft over locating flats by a nut.

Directly above the element are two adjustable resistor spools, each consisting of a fixed-coil portion and a small rheostat.

Resistance R_3 in Figure 4 includes one of these adjustable rheostats. This controls the balance point of the bridge and, consequently, substantially fixes the location of the center-scale point.

Resistance R_7 is similarly adjustable by the other rheostat and by shunting action determines the amount of current in coil B, hence, the length of vector B in Figure 3, and consequently the scale length. Permanency of these adjustments is accomplished by soldering the rheostat contact arms to the windings.



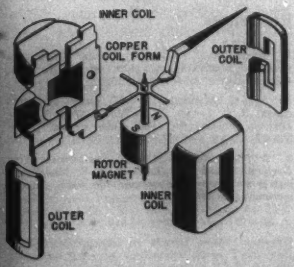
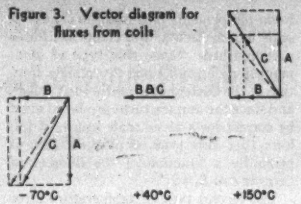


Figure 2. Arrangement of coils and rotor

Figure 3. Vector diagram for fluxes from coils



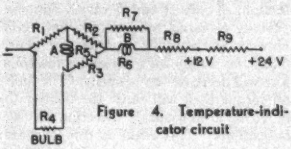


Figure 4. Temperature-indicator circuit

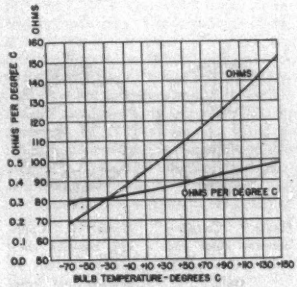


Figure 5. Temperature–bulb-resistance characteristics

how a gradual shortening of vector B, with departure from center scale, makes the scale distribution uniform.

The nonuniform distribution of Figure 7 is approached when a purely cylindrical rotor is used. The uniform distribution of Figure 8 is practically realized if the rotor has flat sides parallel to the rotor-flux lines.

Figures 9 and 10 illustrate the manner in which the flat-sided rotor effects a linear-scale distribution.

The flat-sided rotor produces a large reduction in magnetic coupling between the outer coils and the rotor with rotation away from the center-scale position. This is illustrated by Figures 9 and 10. This effect corresponds to the desired shortening of vector B.

Power-Failure Indication

Power-failure indication is accomplished by a small magnet assembled in the subbridge with the magnetic axis perpendicular to the center-scale rotor axis, so that, in the absence of excitation, the pointer is moved off the lower-scale end. The torque of this small magnet is supplemented by a permeance torque obtained by shaping elliptically the shield enclosing the coil structure, and by aligning the minor axis properly.

Both torques vary in an essentially sinusoidal manner with the permeance torque in second harmonic relationship to that of the small magnet. These torques and their uniform resultant are shown in Figure 11.

The uniform resultant provides adequate torque well beyond the scale ends and eliminates the peak at center scale, thus minimizing the frictional and voltage-error problems.

The down-scale shift in indication, which these torques tend to produce, is corrected by adjustment of R_3, Figure 4.

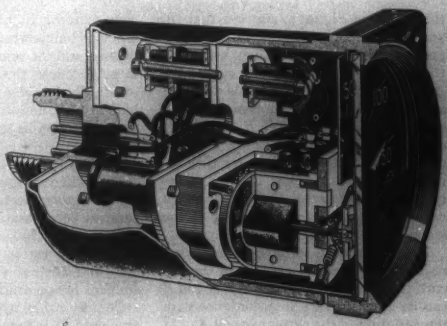


Figure 6. Sectional view of single-element moving-magnet ratio-type temperature indicator

Scale Distribution

In order to attain the required linear scale the introduction of nonlinear effects is necessary. Figure 7 shows the crowding at the scale ends, which would occur if the effective vector B of the small outer coils were constant for every scale position, and if the vector A of the inner coils were of a magnitude proportional to the variation of the indicated quantity from the center-scale value. Figure 8 shows

Voltage Error

Fundamentally, the rotor position depends upon the ratio of the currents in the

two sets of coils and not upon magnitudes. In the absence of pull-off magnet and shield torques, the indication would be independent of applied voltage.

The pull-off magnet and shield torques cause the pointer to move down scale as the supply voltage and, consequently, the torque contributed by the coils are reduced. Reduction of voltage from 28.5 to 22.5 volts generally causes errors less than three degrees centigrade at any scale point.

Ambient-Temperature Compensation

Errors caused by change in ambient temperature are of two types. The first is a change in scale length which is caused by disproportionate changes in the currents in coils A and B. With reference to the right-hand diagram in Figure 3 and the circuit of Figure 4, suppose that the ambient temperature is raised, and suppose that R_7 is omitted. Then, because of the increased resistance of the copper coil A, the current in that coil would decrease, and vector A would be shortened. However, the current in coil B would not change appreciably, and vector B would not change. The dashed vector C shows the resultant in this case. The angle between the solid vector C and the dashed vector C represents a shortening of the scale.

If resistance R_7 of low-temperature-resistance coefficient is placed in the circuit, then the current in the copper coil B can be made to vary in accordance with the variation of the current in coil A. At room temperature a portion of the battery current passes through coil B and is governed by R_6 and R_7. At elevated temperatures a lesser portion of the battery current passes through coil B. With reference to Figure 3 again it is apparent that, if vectors A and B are shortened proportionately, the resultant vector falls on the room-temperature resultant, no change in scale length occurs, and compensation is accomplished. Since this type of compensation depends upon diverting a fraction of the battery current through coil B, and since the ampere turns produced must be correct for a given scale length, it follows that this type of compensation is primarily a function of the number of turns in coil B.

The second type of temperature error is caused by a change in torque as the resistance of coils A and B vary. Suppose that at elevated temperature both coil currents decrease by say ten per cent. Then the torque contributed by the coils also will decrease ten per cent. The pull-off torque then will cause the pointer to move in a down-scale direction for all indications. This effect is compensated by including in bridge arm R_2 a certain amount of positive-temperature-coefficient material, in this case, copper. If the ambient temperature is elevated R_2 increases, and the bridge values change in a sense to cause the pointer to move up scale. Since bridge arm R_2 is opposite to bulb arm R_4, an increase in R_2 acts in the same direction as an increase in bulb resistance.

Self-heating errors are negligible because of the very low heat dissipation and the corrective effects of the ambient-temperature compensations.

Table I includes observed ambient-temperature errors on a typical instrument at −50- and +75-degree-centigrade ambient temperatures.

Compensation attainable is better than required. It is thus possible to use R_7 for both compensating and scale-length-adjusting purposes with satisfactory results.

Factor of Merit

On an equivalent D'Arsonval basis the torque-to-weight ratio of the temperature indicator averages unity with variations of ±20 per cent.

Table I. Observed Ambient-Temperature Errors

Indication—Deg C	Observed Temperature Error—Deg C	
	At −50	At +75
− 70	0.0	−1.0
− 30	−0.5	−0.5
0	0.0	−0.5
+ 30	0.0	−0.5
+ 80	−0.5	+1.0
+120	+1.0	+1.0
+150	−1.0	+1.0

Conclusions

The instrument described has the properties of lightweight, ruggedness, simplicity, and serviceability required for aircraft use. In addition the factor of merit is good, the voltage errors are low, self-heating errors are negligible, and ambient-temperature errors are practically compensated.

The instrument may be adapted to many applications where the characteristics of a ratio instrument are desirable. Inferred uses include the measurement of ohms, current ratios, voltage ratios, telemetering, and voltage-weighted current indications.

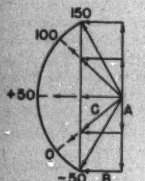


Figure 7. Scale distribution with cylindrical rotor

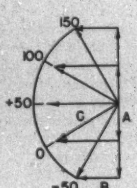


Figure 8. Scale distribution with flatted rotor

Figure 9. Coupling between rotor and outer coils at center scale

Figure 10. Coupling between rotor and outer coils 90 degrees from center scale

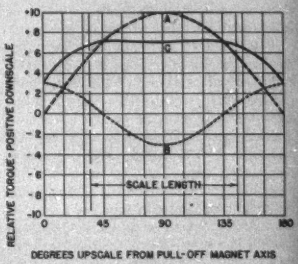


Figure 11

A. Torque curves of pull-off magnet
B. Shield
C. Resultant

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Protection of Large D-C Machines by Means of High-Speed Circuit Breakers

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THE problems of protecting large installations of rotating d-c machines have been neglected to some extent by the lack of suitable high-speed switchgear rugged enough to stand the severe duty usually encountered. The authors are describing their analysis of probable short-circuit characteristics of such large systems and a high-speed breaker rated at 7,500 amperes which has been developed for this particular purpose. The authors are also describing a large rotary-converter installation built some time ago which has recently been modernized by means of modern switchgear in order to overcome the serious damage caused to the rotating machines resulting from the inadequacy of the originally installed switchgear.

Comparison of Short-Circuit Conditions (A-C and D-C)

There has been some confusion in regard to application of ultrahigh-speed breakers. Perhaps the curves shown in Figure 1 can help to clear up this confusion.

Curve 1 is a fully offset 60-cycle current wave. The current dies down after a few cycles and becomes symmetrical, and an attempt to interrupt it at the first one-quarter-cycle peak would merely impose a severe duty on the breaker contacts as they would operate when the maximum current is flowing. The peak electromagnetic forces in the installation will not be cut down by the one-quarter-cycle opening of the breaker. From the standpoint of breaker performance it would be desirable to delay its opening as it then will have to interrupt lower currents. A compromise must be made between system stability and breaker performance and standard a-c breakers usually open in three to five or even eight cycles. Unless system stability is of prime importance there is no material gain in paying the higher cost of high-speed breakers.

Curve 2 is a d-c curve illustrating the condition existing in a system where the d-c generators are located an appreciable distance apart. The rate of rise is very low due to the inductance, and the ultimate current is low due to the ohmic resistance of the system. Except for preventing damage caused by commutator flashovers no gain is made by the use of high-speed breakers and commercial breakers with opening speeds of 1¼ to three cycles can therefore satisfactorily be employed.

Curve 3 shows the d-c rate of rise of a 300-volt 3,000-kw generator under short-circuit conditions. The initial rate of rise is 4,500,000 amperes per second and the ultimate current is 450,000 amperes. A three-cycle breaker would have to interrupt 200,000 amperes and a 1¾-cycle breaker would have to interrupt 125,000 amperes. A ¾-cycle breaker (time to peak) would have to interrupt only 23,000 amperes. Here the value of the high-speed breaker is clearly indicated. The electromechanical stresses in the machine and the connecting bus-bar structure or conductor is only 0.77 per cent when using a high-speed breaker. The various manufacturers of d-c machines do not seem to agree on the initial rate of rise and the ultimate current on a short-circuit condition, and a discussion of this problem would be of interest, but from test data which we have on a 650-volt 6,000-kw machine we have established beyond a doubt that the initial rate of rise is more than 6,000,000 amperes per second. This curve is shown as curve 4.

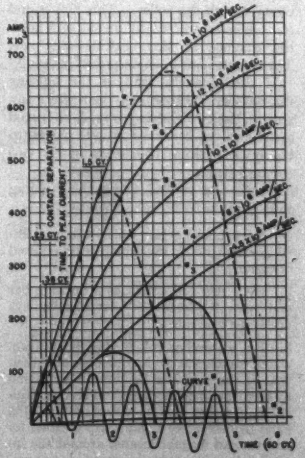

Figure 1. Short-circuit curves comparing effect of opening speed of circuit breakers

As more machines are added to the system, curves 5, 6, and 7 probably apply. If we use a three-cycle breaker in a d-c system represented by curve 7 we will have to interrupt the fantastic current of 700,000 amperes while a 0.38-cycle breaker (time to peak current) would have to interrupt only 80,000 amperes. In this case the stresses are again only 0.77 per cent if a high-speed breaker is used.

Assume a bus of 100-foot length used in this latter system with the busses placed two feet apart and consisting of two six-inch-square tubes, the force per running foot will be 110,000 pounds, requiring insulators spaced 0.064 feet apart if a three-cycle breaker is used. This of course is impractical. If we use a 0.38-cycle breaker (time to peak circuit) the force is only 1,450 pounds per running foot and the insulator spacing of 4.8 feet can be safely employed. This latter scheme would appear to be more reasonable.

It is appreciated that a bus-to-bus fault in a modern installation is rather uncommon but they do occur with disastrous results and it is emphasized that sound engineering practice dictates the installation of modern high-speed switchgear as the one solution to the problems which are encountered by high current and the electromagnetic forces they set up in the system.

Oscillographic Comparison of Current Against Time

Figure 2 shows oscillogram of an *FB* breaker interrupting a short circuit on two 3,000-kw generators at 550 volts, in parallel. The mechanical time of the breaker is 0.212 cycle, time to peak is 0.403 cycle, total time 82 cycles except for the small amount of trailing current which is permitted to flow through the arc interrupter resistors in order to keep the breaker voltage within reasonable limits. The maximum current is 26,600 amperes and the initial rate of rise is 4,920,000 amperes per second. The breaker was tripped by the reverse current feature, which trips the breaker in the shortest time possible.

The oscillogram in Figure 3 shows the breaker interrupting the same circuit but tripped by the forward-current overload feature. Due to the inherent characteristics of the overcurrent feature which employs an open air gap with a moving armature, the breaker now trips somewhat slower. The mechanical time of the breaker is 0.5 cycle, time to peak current is 0.667 cycle, and the total time is 1.17 cycles. The maximum current is 36,200 amperes or 9,600 amperes more than the current is in Figure 2 because

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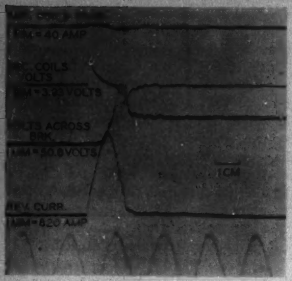


Figure 2. Oscillogram of *FB* breaker interrupting 550-volt d-c reverse-current trip

the mechanical time of the breaker is 0.288 cycle slower.

Figure 4 shows the same breaker opening the same circuit but at 650 volts and tripped by the forward current trip. The mechanical time is again 0.5 cycle, peak 0.645 cycle, total time 1.16 cycles, and maximum current 47,000 amperes, an increase of 8,700 amperes by increasing the generator voltage by 100 volts over Figure 3.

Description of Type-FB Breaker

A schematic cross section of the *FB* breaker is shown in Figure 5. The current path through the breaker is from the upper terminal through the magnetic blowout coil to the upper contact. From here it flows through the bridges to the lower contact where the circuit divides into two parallel circuits which then meet in the lower terminal.

There are two blowout coils, one located on each side of the arc chute and connected in parallel. Each coil consists of one turn and the coils are physically located so that the core of the coil is in line with the region in which the arc is originated. The return path for the blowout flux is through a laminated-iron circuit. The laminations extend through the core of the blowout coil to the outside face of the arc chute so there is no time delay in building up the blowout flux due to eddy current. Two slotted pole faces extend from the extremity of the laminated core to distribute the flux for proper arc interruption.

The movable bridge contacts are supported in an extremely light carrier made of heat-treated aluminum and the movable arcing contacts are in turn mounted on this carrier. The necessary contact pressure between the stationary and moving contacts is furnished by a completely independent separate spring on each contact located between the contact and the contact carrier.

The carrier is biased toward the open position by means of two opening springs, one located inside the other. The stronger of the two opening springs has a limited stroke and acts on the contact carrier only during the initial acceleration period. The weaker of the two springs is active during the whole opening stroke and definitely holds the contact carrier in its open position. The kinetic energy stored up in the moving contact

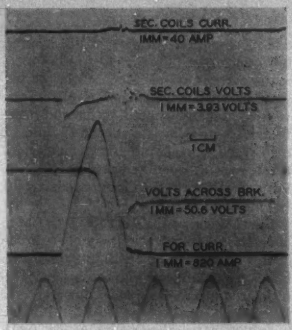


Figure 3. Oscillogram of *FB* breaker interrupting 550-volt d-c forward-current trip

during the opening stroke is absorbed at the end of the stroke by means of a friction-type buffer, preventing rebound of the contacts.

The contact carrier is held in the closed position by means of a clutch shown in the released position on Figure 6. This clutch consists of two hardened steel jaws. The two jaws contact a hardened steel roller on opposite sides. The opening force of the breaker which is 5,000 pounds tends to force the two jaws apart with a force of 300 pounds, due to their angle of contact with the roller. This 300-pound force is counteracted by means of a holding magnet of the bucking-bar type. The magnet has been described in detail.[1]

If the magnetic pull of the holding magnet is temporarily lost for any reason, the two clutch jaws will be forced apart and the breaker contacts moved to the open position by means of the two opening springs.

There are several ways the holding force may be lost:

1. By a bucking bar which will momentarily demagnetize the armature on reversal of current.

2. By a trip coil acting as a bucking bar and connected across the interpole windings of the d-c machines.[2]

3. By a mechanical prying mechanism which exercises a prying force greater than that of the magnetic holding force tending to keep the breaker closed. This mechanical mechanism can be operated by (*a*) a hand trip lever, (*b*) a shunt trip magnet, (*c*) an overload magnet located around the inductive leg of the trip circuit, or (*d*) an overload magnet located around the lower terminal.

As already explained the circuit from the lower contact to the lower terminal is divided in two paths. The upper path passes through the holding magnet and the lower path is surrounded by a stack of iron laminations. With a steady current flowing through the breaker the current will divide between the two paths proportional to the conductances of the two paths. This is true whether the current flows in a forward or reverse direction. With a rapidly changing current flowing through the breaker, the current will divide in the two paths inversely proportional to the inductances of the two paths. This is also true whether the current is flowing forward or in a reverse direction.

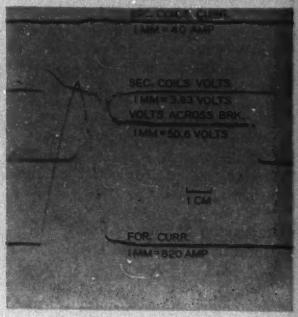


Figure 4. Oscillogram of *FB* breaker interrupting 650-volt d-c forward-current trip

On a quickly rising reverse current, the portion of the current which flows through the holding-magnet circuit will cause the holding flux through the armature to be diverted to a magnetic bypass. The armature will momentarily lose its pull and the breaker will trip for this reason. On slowly rising reverse current

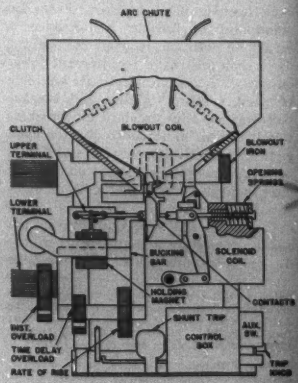


Figure 5. Section of type-*FB* breaker

the same effect will be obtained but at a higher current value.

If we place an overload magnet on the inductive part of the circuit, the overload magnet can be arranged to trip the breaker at a maintained current of sufficient value. A quickly rising current will pass harmlessly through the upper portion of the circuit due to the inductance of the lower circuit. This effect will afford overload protection of the machine and will permit harmless surges to pass through the breaker without tripping it. In other words, a time-delay overcurrent protection is provided without any mechanical timing means.

An overcurrent feature placed on the lower terminal leads where all the current which flows through the breaker will pass through this feature can be arranged to trip the breaker on excessively high current thereby tripping the breaker if its associated machine should contribute a high value of current into a fault on the system.

The operating mechanism consists of a solenoid which is arranged to close the breaker through an overcenter toggle mechanism. The opening springs and the contact buffer are built as an integral part of the closing mechanism. Therefore, all mechanical stresses in the breaker (except the contact pressures) are located in one common assembly and are not transmitted through any insulating material.

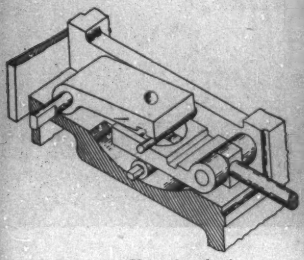


Figure 6. *FB* breaker clutch
Released position

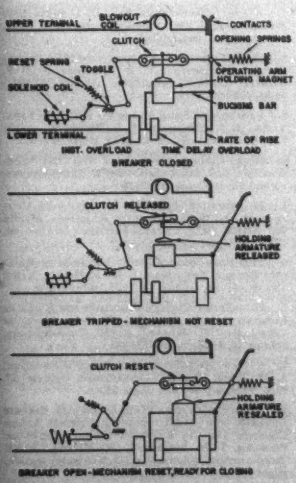


Figure 7. Schematic diagram of *FB* operating mechanism

The various operating positions of the breaker are shown diagrammatically in Figure 7.

The top illustration shows the breaker closed. The opening forces in the breaker are here counteracted by means of the operating toggle which is locked over center.

The center illustration shows the breaker in the tripped position. The clutch is shown in its released position and the contact has been moved to the open position by means of the opening springs. The solenoid mechanism has not yet reset.

The bottom illustration shows the mechanism reset and ready for closing. This resetting was accomplished by means of the resetting spring causing the toggles to fold up thereby resetting the solenoid to its open position which in turn has permitted the two clutch jaws to engage the clutch roller.

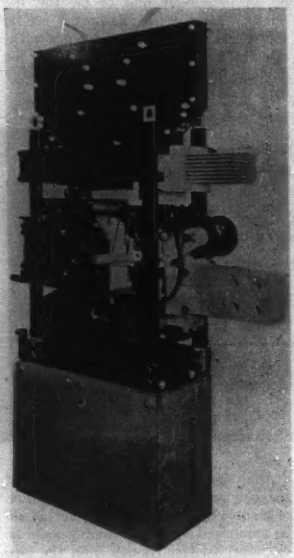


Figure 8. Right-side view of *FB* breaker

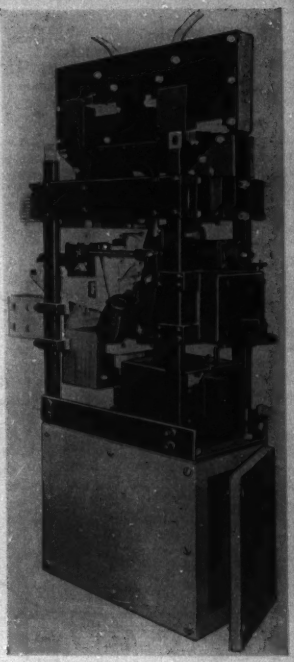


Figure 9. Left-side view of *FB* breaker

The arrangement provides trip-free operation at any part of the closing stroke. Hand operation is provided by means of a removable handle which can be inserted in a socket on one of the toggle links.

Two partial side views of the breaker are shown in Figures 8 and 9.

Description of Rotary-Converter Station

It will be of interest to describe a large d-c installation where the *FB* breakers are being installed to provide better protection of the rotating machines than was originally furnished for this installation. This plant has an installation of a large number of 2,500-kw 60-cycle rotary converters housed in two conversion stations. Only one station is being modernized and this station is described in detail.

The rotary stations are fed by a large hydroelectric power system with interconnections to other power systems. Fault capacities are very high in the a-c system, 1,500,000 kva on the 13.2-kv bus.

The station has double 13.2-kv a-c busses. The double-bus arrangement permits feeding all of the stations from one bus or splitting the load between the two busses. A one-line diagram of the

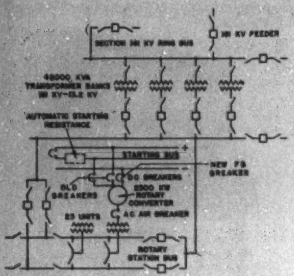


Figure 10. One-line diagram of rotary-converter station and bus

These units were considered very large when installed in 1914 and were quite sensitive to disturbances, particularly those involving rapid changes in frequency. During such disturbances the units tend to pull out of step with each other and flash over. Such troubles often result in damage to the unit, particularly the main and equalizer busses, brush rigging, and commutators. There is also occasional damage to the armature winding. Flashover may also be started by trouble on an individual unit or on the d-c busses. Most of the flashovers are on the d-c side, although there are occasionally a-c flashovers. Most of the damage during flashovers is from energy from the d-c bus.

2. Overload trip on the inductive leg, affording machine overload protection and permitting harmless surges to pass through the breaker.

3. Instantaneous high overload protection which will operate the breaker should any rotary converter contribute a larger amount of forward current into a commutator flashover on any of the machines connected to the bus.

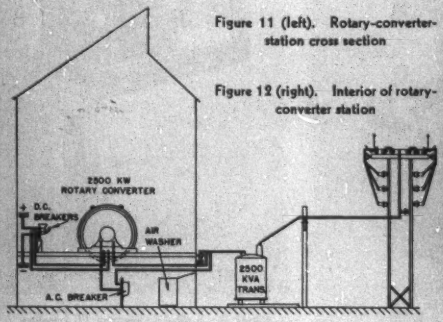
4. Shunt trip.

5. Hand trip.

It is felt that this advancement in the state of the art of circuit-breaker design will materially reduce damage in this station during faults and that the time of outage of load may be materially reduced.

Figure 11 (left). Rotary-converter-station cross section

Figure 12 (right). Interior of rotary-converter station



busses and station is shown in Figure 10. Double disconnecting switches are provided for each unit, permitting the units to be connected to either of the busses. These disconnecting switches will break transformer magnetizing current. The transformers were originally connected to the busses through oil circuit breakers. These have been removed and replaced with low-voltage air circuit breakers of 150,000 amperes interrupting capacity between the transformer secondary and the rotary converter.

Each unit has a positive, negative, and starting air circuit breaker on the d-c terminals as shown in Figure 13. These breakers were originally conventional air circuit breakers, opening in approximately eight cycles. The rotary converters are started from the d-c side by reduced-voltage starting. One unit is provided with an a-c motor for starting in case of complete station outage and there is a similar equipment in the other station to provide alternate means of starting. Several machines, and at times all machines, are operated in parallel on the d-c busses. The physical arrangement of the station is shown in Figure 11. Figure 12 shows the interior of the station.

Analysis of the troubles indicates that the damage to units and the transmission of trouble from one unit to others could be minimized if units in trouble could be disconnected fast enough from the bus. It is felt that the speed of the d-c breakers must be particularly high to be effective in this regard. This high speed will reduce the time of heavy power inflow to the flashover and clear before the inflow can reach its peak, thereby limiting damage and the extension of the disturbance to other units. With the widespread use of mercury-arc rectifiers in the conversion field, new high-speed switchgear of improved design over that previously available was developed. It was decided that the d-c breakers would be replaced with a modern high-speed breaker of the *FB* type.

The breakers in this installation employ the following tripping schemes:

1. Reverse-current protection by means of the bucking bar releasing the holding armature. As it is necessary to start the machines from the d-c bus, a slowly rising reverse current of approximately 1,600 amperes is permitted to pass safely through the breaker but a higher reverse current or a fast-rising reverse current of a lower value will trip the breaker.

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Transient Performance of Induction Motors

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IT has been the usual practice to solve induction-motor transient problems either on the basis of the familiar steady-state equivalent circuit or by calculations which require simplifying assumptions. These methods neglect important factors determining the performance. This paper shows the necessity of considering for many practical problems the electrical and mechanical transient phenomena simultaneously.

For example, during sequential operations such as jogging and plugging, conditions inside the rotor, phase relations, and magnitudes of fluxes and current are influenced both by the electrical transients and by the mechanical slip and oscillation. Also, the residual stator and rotor currents and the angular displacement of the rotor affect performance during plugging; these have been neglected previously.

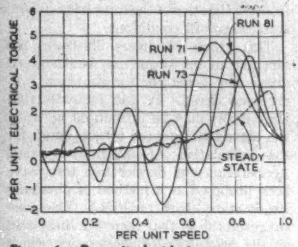

Figure 1. Per unit electric torque versus per unit speed

Effect of rotor deceleration. Transient speed–torque curves with constant rotor deceleration from steady-state conditions at 0.99 per unit speed

Run 71— 6 cycles for unit speed change
Run 81—12 cycles for unit speed change
Run 73—24 cycles for unit speed change

In order to evaluate some of these mutually interrelated phenomena which had not been analyzed previously, the induction-motor equations including the rotor mechanical load and inertia were set up on the General Electric Company differential analyzer.[1] Since it was desired to investigate a number of different operating conditions, the machine characteristics were held constant in all but a few cases. These characteristics given in Appendix B are those of a low-resistance motor which tend to accentuate the motor transients. The effect of increased rotor resistance may be seen in Figure 15. The results and conclusions presented in this paper indicate the importance of considering the transient electrical and mechanical phenomena simultaneously.

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The authors express their appreciation to S. B. Crary for having suggested this problem and for his constructive criticism; to C. Concordia for his suggestions and discussion; and to members of the staff of the differential analyzer.

Assumptions

The analysis and results are based on the following assumptions (which are similar to those of reference 2).

1. Balanced windings are assumed on both rotor and stator.

2. The mutual inductance between any stator and rotor winding is considered to be a cosinusoidal function of the electrical angle between the axes of the two windings.

3. It is assumed that the rotor is smooth and that the self-inductance of any winding is independent of rotor position.

4. The effects of saturation, hysteresis, and eddy currents are neglected.

5. The machine impedances are assumed to be independent of rotor speed.

6. The machine electrical neutral is assumed ungrounded.

7. In all cases studied, the motor is considered connected to an infinite bus through negligible impedance. The effect of system impedance can be taken into account by increasing the stator impedance, that is, by moving the infinite bus from the terminals of the machine and placing it further back in the system.

Conclusions

1. Large errors may be introduced by using the steady-state speed-torque curve for the calculation of transients.

2. Under transient conditions, motor torque can be developed at speeds above synchronous, and generator torque can be developed at speeds below synchronous.

3. Transient electric torques under shock mechanical loads or sudden electrical disturbances can be several times the steady-state pullout torque.

4. Transient electric-torque oscillations incident to a sudden change in applied voltage are, in general, more severe than those due to a sudden change in mechanical load.

5. The initial rate of change of electric torque with respect to speed following a sudden change in mechanical load is less than the steady-state speed-torque curve would indicate.

6. For a sudden change in applied voltage the transient electric torque is unaffected by the electrical angle at which the voltage is changed, provided that the machine was not initially running open-circuited with trapped flux.

7. Transient-torque oscillations following the sudden application of voltage to a machine containing trapped flux (as in jogging) can be much more severe than the transient torques incident to a short circuit at the motor terminals.

8. With a machine temporarily disconnected from the system and running with trapped rotor flux, there are definite optimum times for reapplication of voltage in order to reduce the torque oscillations.

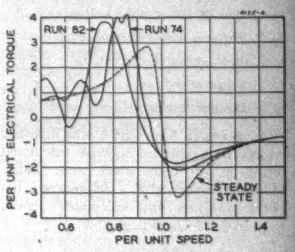


Figure 2. Per unit electric torque versus per unit speed

Effect of rotor deceleration. Transient speed–torque curves with constant rotor deceleration from steady-state conditions at 1.5 per unit speed

Run 82—12 cycles for unit speed change
Run 74—24 cycles for unit speed change

9. The magnitude of transient plugging torque is greatly affected by the magnitude of the trapped rotor flux and its position relative to the stator. It is also affected by motor speed.

10. Transient currents caused by jogging or plugging (with trapped rotor flux) may be larger than the steady-state full-voltage starting current.

Method of Solution

The equations of induction-motor performance (see equations 10 through 20, Appendix A) were set up on the General Electric Company differential analyzer.[1] An inspection of these equations will show that 14 separate integrations were required in the solution. In this respect the problem provided an excellent oppor-

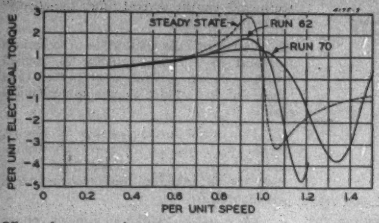
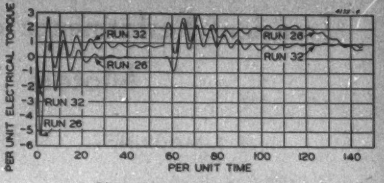


Figure 3 (left). Per unit electric torque versus per unit speed

Figure 4 (right). Per unit electric torque versus per unit time (electrical radians)



Effect of rotor acceleration
Transient speed-torque curves with constant rotor acceleration from steady-state conditions at zero speed
Run 70— 6 cycles for unit speed change
Run 62—24 cycles for unit speed change

Effect of voltage disturbance; steady-state full-voltage conditions for 0.99 per unit speed before zero time
Run 32—Voltage reduced to 0.5 per unit at $t=0$. Voltage restored to 1.0 per unit at $t=18\pi$ (9 cycles)
Run 26—Terminals short circuited at $t=0$. Voltage restored to 1.0 per unit at $t=18\pi$ (9 cycles)

tunity to observe and judge the operation of the analyzer, when using the entire integrator capacity. Five quantities, obtained as outputs from the analyzer, were plotted as functions of time. These were:

(*a*). One of the applied voltages, E_a.*

(*b*). Phase α stator current, I_α.

(*c*). Phase β stator current, I_β.

(*d*). Rotor speed, $p\theta$.

(*e*). Electric torque, T_e.

As shown in Appendix C, the analyzer results were checked against calculated results in two cases which were readily soluble analytically. Differences between analyzer and calculated results were in both cases negligible.

Discussion of Results

A. Electric Torques Caused by Rotor Acceleration — Transient Torque-Speed Curves

In order to study the transients due to changing rotor speed as differentiated from those due to electrical disturbances, the machine was subjected to various constant rotor accelerations and decelerations. The electric torques developed in some of these cases are shown in Figures 1, 2, and 3.

In Figure 1, the motor was assumed in all three cases to be operating initially under steady-state conditions with a slip of one per cent. The rotor was then decelerated in runs 71, 81, and 73 at rates corresponding to unit change of speed in 6, 12, and 24 cycles, respectively, of fundamental frequency. It is of interest to note that the initial rate of change of torque with speed is zero and that the electric torque oscillates about the steady-state speed-torque curve. That the initial rate of change of torque with speed is zero, of course, is due to inductive lags in the motor. The relation of the first swings of these curves may be explained as follows:

1. If the rotor were decelerated at an infinitely slow rate, the torque would follow its steady-state speed-torque curve.

2. If the rotor were decelerated at an infinitely fast rate, the torque would remain constant at its initial value because of inability of the motor to respond electrically to the infinite deceleration.

It is seen, then, that the speed-torque curves of runs 71, 81, and 73 appear in a logical sequence between the limiting curves resulting from zero and infinite deceleration.

Figure 1 also shows that appreciably higher-peak electric torque may be developed upon the sudden application of mechanical load than the steady-state theory would indicate, and at a different speed.

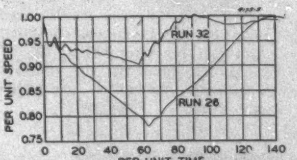


Figure 5. Per unit rotor speed versus per unit time (electrical radians) for cases shown in Figure 4

Figure 2 illustrates results obtained when the motor was decelerated from initial steady-state conditions for a rotor speed of 1.5 (per unit).

The curves shown in Figure 3 resulted from acceleration of the rotor from steady-state standstill conditions.

This group of curves illustrates the fact that motor torque may be developed above and generator torque below synchronous speed. It also indicates that large errors may be introduced by using the steady-state speed-torque curve for the calculation of severe transients. Acceleration and deceleration tests have been proposed as a method of obtaining steady-state characteristics.[3] The present results show that there is a limitation on the magnitude of acceleration which can be used in such tests if the true steady-state behavior is to be obtained.

B. Electric Torques Due to Sudden Change in Applied Voltage

Figure 4 shows the effect upon electric torque of sudden changes in applied voltage. For both runs 32 and 26 of Figure 4, the motor was initially operating at steady-state conditions with a slip of one per cent. A constant mechanical load torque was assumed in both cases, although arbitrary load-torque curves as a function of speed easily could have

* See Appendix B for list of nomenclature.

Shows one cycle of steady-state current before zero time

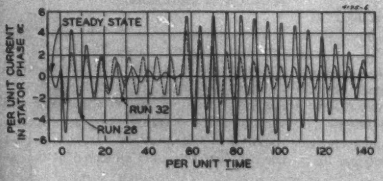
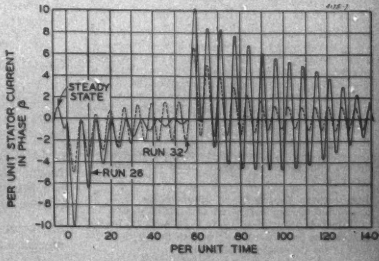


Figure 6 (left). Per unit stator current in phase α versus per unit time (electrical radians) for cases shown in Figure 4

Figure 7 (right). Per unit stator current in phase β versus per unit time (electrical radians) for cases shown in Figure 4

Shows one cycle of steady-state current before zero time



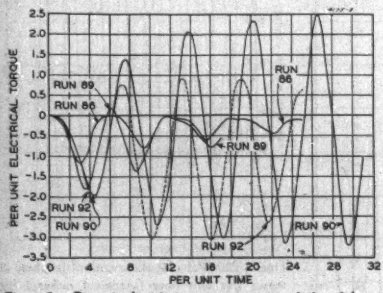
been used if desired. An inertia constant (H) of approximately 0.45 was assumed for motor and load combined.

In run 26, at $t=0$, (also $E_\beta=0$), the applied voltage suddenly was reduced to zero, corresponding to a zero-impedance short circuit at the motor terminals. As is seen from an inspection of Figure 4, the maximum electric torque following the application of a short circuit is of the order of five per unit. It is also seen, as would be expected, that the electric torque became zero after the transients had died out and remained zero until the short circuit was removed. The fault was removed nine cycles after its application. The torque recovery following the removal of short circuit also is pictured in Figure 4.

Run 32, which also has been plotted in Figure 4 for purposes of comparison, is similar to run 26, except that the applied voltage was reduced suddenly to half value rather than to zero.

Several runs also were made in which the electrical angle at which the voltage was reduced or restored was varied. As stated in the conclusions, the electrical angle of switching under these conditions had no effect on the ensuing electric torque for a given switching time.

Figure 5 shows the per unit speed as a function of time for runs 26 and 32. The two-phase stator currents I_α and I_β for these two runs are plotted in Figures 6 and 7, respectively. As shown in Appendix A, corresponding three-phase currents may be obtained from I_α and I_β by means of a relatively simple manipulation; in fact, in the present treatment I_α itself is one of the three-phase currents.



Effect of rotor speed on plugging torque. Infinite-inertia machine running at various positive speeds with zero rotor flux. Unit voltage of negative phase rotation applied at zero time

Run 86—Rotor speed = 1.00 per unit
Run 89—Rotor speed = 0.50 per unit
Run 92—Rotor speed = 0.15 per unit
Run 90—Rotor speed = 0 per unit

Figure 8. Per unit electric torque versus per unit time (electrical radians)

C. Plugging Torques

Two extreme plugging conditions are those in which the machine is plugged instantaneously while running at rated speed and load, and while it is running at rated speed but after the rotor flux has died out completely. Plugging torques from runs which are nearly these extremes are shown in Figure 10.

Run 85 was obtained as follows:

1. With the motor running at steady-state conditions with a slip of one per cent, the stator phase β was opened at a zero of I_β.
2. Phase α of the stator was opened approximately one-fourth cycle later at a zero of I_α.
3. At the same instant that phase α was opened, voltage of opposite (negative) phase rotation was applied simultaneously to both stator phases. (In this case, the mechanical load torque was assumed to be constant at its initial value, and the inertia constant (H) was assumed to have a value of approximately 1.43.) This is obviously almost one of the extreme cases mentioned before.

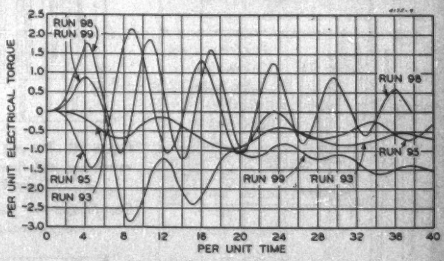


Figure 9. Per unit electric torque versus per unit time (electrical radians)

Effect of rotor speed on plugging torque. Infinite-inertia machine running at various negative speeds with zero rotor flux. Unit voltage of negative phase rotation applied at zero time

Run 95—Rotor speed = −0.25 per unit
Run 93—Rotor speed = −0.50 per unit
Run 99—Rotor speed = −0.75 per unit
Run 98—Rotor speed = −1.00 per unit

The two phase currents for this run are on Figures 11 and 12.

Run 86 was obtained by applying negative-phase-rotation voltage to an infinite-inertia machine running at synchronous speed with zero rotor flux. It is the other extreme case and is compared with run 85. The effect of trapped rotor flux is seen to be very important.

It is interesting to note the similarity between run 86 of this paper and run 36 of reference 4, in which the machine constants are similar to those used in this study.

Figures 8 and 9 have been included to show the effect of rotor speed upon plugging torque. All curves shown in these two figures are based on the assumptions that the motor was initially unexcited, contained no trapped flux, and had infinite rotor inertia, negative phase rotation of voltage being applied in all cases.

Figure 9 shows torques which are not, strictly speaking, "plugging" torques since the phase rotation of the applied voltage is in the same direction as the motor rotation. However, they are of interest in that they extend the range of rotor speed. Such conditions may be encountered in some pump and propeller drives having more than one motor on the same shaft.

D. Reclosing of Stator Circuit With Trapped Flux in the Rotor

Several cases were studied in which the stator was open-circuited from a steady-state full-load running condition. After several cycles, full voltage was reapplied. Figures 13 and 14 show the electric torque and speed respectively for a few of these cases. It will be seen from these curves that there is at least one definite optimum reclosing time both from the standpoint of torque oscillations and from that of speed-recovery time. That there are several of these optima, and that they depend on machine inertia and rotor resistance may be seen from the following analysis.

In the steady state with the motor running at approximately one per cent slip, the rotor flux rotates at synchronous speed and lags the stator flux by a definite angle. It is continually slipping forward with respect to the rotor. When the stator is open-circuited, the rotor flux becomes fixed in the rotor and decays relatively slowly (with the rotor open-circuit time constant L/r_r) from its initial value. Since the electric torque is zero, the rotor slows down so that the trapped and slowly decaying rotor flux lags at an increasing rate behind the

steady-state position of the stator flux.

An understanding of the phenomena occurring when the stator circuit is again closed on the supply voltage may be obtained by regarding the induction motor as a synchronous machine running below synchronism, the trapped rotor flux taking the place of the synchronous-machine excitation. The sudden re-application of stator voltage produces two fluxes, one very nearly the steady-state rotating field, the other a stationary (and decaying) field. Now the machine time constants are much shorter than with the stator open-circuited, so that the stationary field components decay more rapidly, but for the purposes of the argument one may neglect this decay. Both stator fields react on the rotor flux, the steady-state rotating component producing a slip-frequency torque, the stationary component producing a speed-frequency component. If the slip is small, the slip-frequency component acts roughly as a "synchronizing" torque, so that it is evident that there is a preferred initial position of the rotor for minimum time to recover speed, while the speed-frequency component produces only a superposed vibration of the rotor speed. One may calculate from the initial slip and rate of increase of slip the relative angle through which the rotor has passed, and it then will be found that at first for very small angles of retardation the speed will recover quickly and with a minimum of disturbance. Then, as the angle exceeds 90 degrees, the initial accelerating torque becomes smaller and finally is not sufficient, so that the machine speed at first may decrease further by an appreciable amount. As in the equivalent synchronous-machine case, the "worst" angle lies only a relatively short distance behind the "best" angle. The situation is made more complex by the fact that in every slip cycle the slip becomes greater and the trapped flux becomes smaller, so that the variation with angle becomes much less pronounced. The present case has a rather low rotor

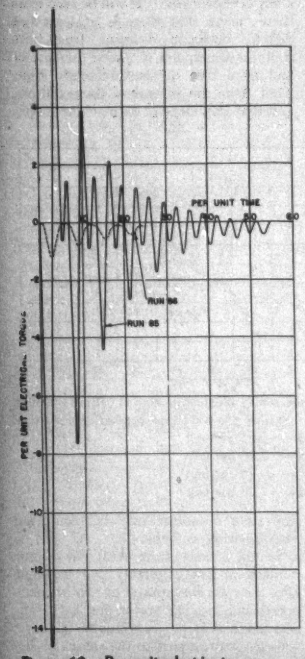


Figure 10. Per unit electric torque versus per unit time (electrical radians)

Effect of trapped rotor flux on plugging torque
Run 85—Plugging from steady-state conditions for 0.99 per unit speed (see section C)
Run 86—Plugging an infinite-inertia machine running at synchronous speed with zero rotor flux

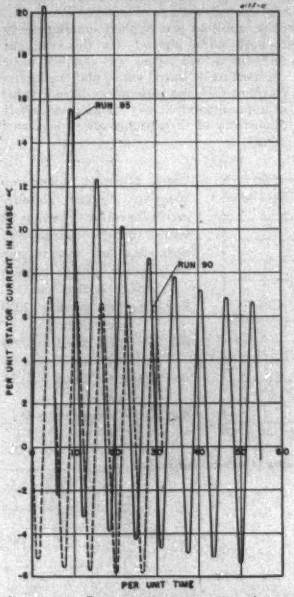


Figure 11. Per unit stator current in phase α versus per unit time (electrical radians) for runs 85 and 90

See Figures 10 and 8, respectively, for corresponding electric torque

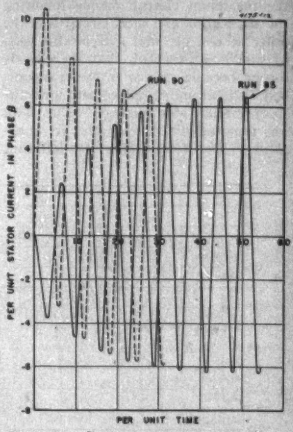


Figure 12. Per unit stator current in phase β versus per unit time (electrical radians) for runs 85 and 90

See Figures 10 and 8, respectively, for corresponding electric torque

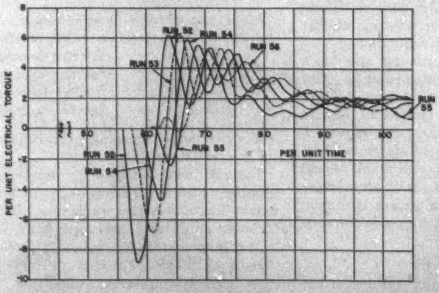


Figure 13. Per unit electric torque versus per unit time (electrical radians)

Effect of switching angle. Steady-state full-voltage conditions for 0.99 per unit speed before zero time. Stator open-circuited at $t=0$
Run 52—Voltage restored to 1.0 per unit at $t=18\pi$ (9 cycles)
Run 53—Voltage restored to 1.0 per unit at $t=18.5\pi$ (9¼ cycles)
Run 54—Voltage restored to 1.0 per unit at $t=19\pi$ (9½ cycles)
Run 55—Voltage restored to 1.0 per unit at $t=19.5\pi$ (9¾ cycles)
Run 56—Voltage restored to 1.0 per unit at $t=20\pi$ (10 cycles)

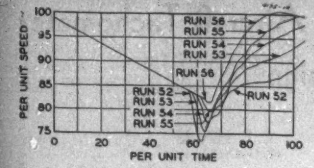


Figure 14. Per unit speed versus per unit time (electrical radians) for runs 52–56

See Figure 13 for corresponding electric torque

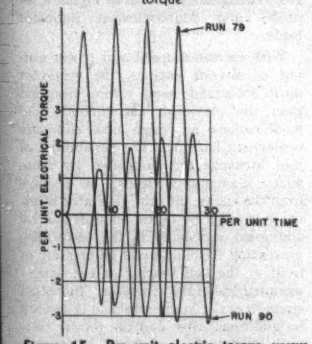


Figure 15. Per unit electric torque versus per unit time (electrical radians)

Effect of rotor resistance. Full voltage applied to locked rotor machine

Run 79—Rotor resistance = 0.04 per unit. Positive-phase-rotation voltage

Run 90—Rotor resistance = 0.01 per unit. Negative-phase-rotation voltage

resistance, so that the effect is still large in the second slip cycle which has been studied. The inertia of the machine evidently enters here also, as it determines the rate of increase of slip. A motor with a small inertia and a high rotor resistance would show little variation with angle, and the ratio of inertia to rotor resistance may form a rough criterion of the importance of the effect of angle. Also if the slip becomes very large, the effect of the stationary stator flux may be emphasized and a pronounced speed decrease consequently may be observed. In all cases, the severity of the rotor swings should tend to be less than in the synchronous-machine case because of the generally higher resistances and the fact that the rotor has no sustained rotor excitation and thus no preferred position in which it must come to equilibrium.

E. Transient Currents

If we consider only the a-c component of current, it is seen from Figures 6 and 7 that the current caused by a terminal short circuit is somewhat less than full-voltage starting current; however, that resulting when the fault is removed is approximately equal to full-voltage starting current.

It is interesting to note that the current caused by plugging (when the rotor contains trapped flux) may be much larger than full-voltage starting current. For the case illustrated in Figures 11 and 12, the maximum current is nearly twice the normal starting value.

Appendix A. System Equations

The equations whose solution forms the basis for the results of this study have been derived by Stanley.[3] These equations in which all quantities have been referred to the stator may be written

$$e_\alpha = p\psi_\alpha + r_s i_\alpha + \psi_\beta(p\theta) = 0 \tag{1}$$

$$e_\beta = p\psi_\beta + r_s i_\beta - \psi_\alpha(p\theta) = 0 \tag{2}$$

$$\psi_\alpha = G(p)E_\alpha + x(p)i_\alpha \tag{3}$$

$$\psi_\beta = G(p)E_\beta + x(p)i_\beta \tag{4}$$

$$T_e = \psi_\beta i_\alpha - \psi_\alpha i_\beta \tag{5}$$

$$p\theta = \frac{1}{H'}\int (T_e - T_m)dt \tag{6}$$

$$\theta = \int p\theta dt \tag{7}$$

$$E_\alpha = E\cos t \tag{8}$$

$$E_\beta = E\sin t \tag{9}$$

where

$$G(p) = \frac{M}{Lp + r_s}$$

$$x(p) = \frac{L(x'p + r_s)}{Lp + r_s}$$

$$x' = L - \frac{M^2}{L}$$

All quantities are defined in Appendix B.

For solution on the differential analyzer, these equations are written in the following form:

$$\psi_\alpha = -r_s\int i_\alpha dt - \int \psi_\beta d\theta \tag{10}$$

$$\psi_\beta = -r_s\int i_\beta dt + \int \psi_\alpha d\theta \tag{11}$$

$$x'i_\alpha = \psi_\alpha + \int\left(\frac{r_s}{L}\psi_\alpha - \frac{M}{L}E_\alpha - r_s i_\alpha\right)dt \tag{12}$$

$$x'i_\beta = \psi_\beta + \int\left(\frac{r_s}{L}\psi_\beta - \frac{M}{L}E_\beta - r_s i_\beta\right)dt \tag{13}$$

$$E_\alpha = -\int E_\beta dt \tag{14}$$

$$E_\beta = \int E_\alpha dt \tag{15}$$

$$T_e = \int \psi_\beta di_\alpha + \int i_\alpha d\psi_\beta - \int \psi_\alpha di_\beta - \int i_\beta d\psi_\alpha \tag{16}$$

$$p\theta = \frac{1}{H'}\int (T_e - T_m)dt \tag{17}$$

$$\theta = \int p\theta dt \tag{18}$$

Equations 10 through 18 which require 14 integrators were set up on the differential analyzer, and a number of solutions was obtained. The quantities plotted were electric torque, rotor speed, applied voltage, and the two components of stator current. The latter do not appear explicitly in equations 10 through 18 but come directly from the definition of flux; namely:

$$I_\alpha = \frac{1}{M}(\psi_\alpha - Li_\alpha) \tag{19}$$

$$I_\beta = \frac{1}{M}(\psi_\beta - Li_\beta) \tag{20}$$

From the definitions of the α and β quantities,[2] the stator-phase currents for a three-phase machine in terms of I_α and I_β are (with no zero-sequence currents):

$$i_a = I_\alpha \tag{21}$$

$$i_b = -\frac{1}{2}I_\alpha + \frac{\sqrt{3}}{2}I_\beta \tag{22}$$

$$i_c = -\frac{1}{2}I_\alpha - \frac{\sqrt{3}}{2}I_\beta \tag{23}$$

Appendix B. Nomenclature and Values of Parameters for Machine Studied

All quantities are in per unit on kilovolt-ampere base.

L = apparent three-phase stator and rotor self-inductance = 3.07
M = apparent three-phase mutual inductance = 2.99
r_s = resistance of one stator phase = 0.01
r_r = resistance of one rotor phase = 0.01
$p\theta$ = rotor speed
t = time in electrical radians at unit speed
θ = electrical angle between rotor phase α and stator phase α at any time t
$p = d/dt$
I_α = stator current in positive α axis
I_β = stator current in positive β axis
E_α = stator terminal voltage in positive α axis
E_β = stator terminal voltage in positive β axis
E = maximum value of terminal voltage
ψ_α = rotor-flux linkages in positive α axis referred to stator
ψ_β = rotor-flux linkages in positive β axis referred to stator
i_α = rotor current in positive α axis referred to stator
i_β = rotor current in positive β axis referred to stator
e_α = rotor terminal voltage in positive α axis referred to stator = 0
e_β = rotor terminal voltage in positive β axis referred to stator = 0
H' = rotor moment of inertia = 338.0
H = conventional inertia constant $= H'/4\pi$ (frequency) = 0.448
T_e = induction-motor torque
T_m = mechanical load torque = 0.91
i_a = stator current in phase a
i_b = stator current in phase b
i_c = stator current in phase c
λ_1, λ_2 = roots of characteristic equation (locked rotor)

$\omega = 2\pi \times$fundamental applied frequency $= 1.0$

$\phi =$ power-factor angle (locked rotor)

$$= \tan^{-1} \frac{\lambda_1\lambda_2 - \omega^2}{\omega(\lambda_2 + \lambda_1)}$$

$$\theta_1 = \tan^{-1} \frac{\omega^2 + \lambda_1\lambda_2}{\omega(\lambda_2 - \lambda_1)}$$

Appendix C

As a check on the differential-analyzer accuracy, the torque–time curves of two of the simple cases were checked by calculation. An exact expression for the electric torque with blocked rotor and simultaneous application of voltage in both axes (on the basis of the given assumptions) is found in equation 5 of reference 5. This equation may be reduced to

$$T_e = T_s \left[1 + \varepsilon^{-(\lambda_1+\lambda_2)t} - \frac{\varepsilon^{-\lambda_1 t} \cos(\omega t + \theta_1) + \varepsilon^{-\lambda_2 t} \cos(\omega t - \theta_1)}{\cos \theta_1} \right]$$

where

$$\theta_1 = \tan^{-1} \frac{\lambda_1\lambda_2 + \omega^2}{\omega(\lambda_2 - \lambda_1)}$$

This is identical in form with the approximate equation 11 of reference 6, the difference being found in the phase angle θ_1 which replaces ϕ of Kilgore and Wahl[6] where ϕ is

$$\phi = \tan^{-1} \frac{\omega^2 - \lambda_1\lambda_2}{\omega(\lambda_2 + \lambda_1)}$$

This difference amounts to three per cent in the maximum torque for the machine constants used in the greater part of the study. The calculation of torque was carried out for four or five cycles of each of two cases (runs 90 and 79) Figure 15, and the discrepancy between calculated and analyzer solutions was found to be negligible. The two-phase currents corresponding to run 90 are given in Figures 11 and 12.

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Recent Advances in Aircraft Tachometer Design

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Synopsis: A discussion of recent developments in magnetic-drag-type aircraft tachometer equipment. Wartime demands for increased temperature range, instrument durability, and compactness have led to certain revisions and new design features. The results of these recent developments are outlined in this paper.

THE magnetic-drag tachometer system consists of a three-phase generator supplying power to a synchronous motor in an indicator (Figures 1 and 2). The generator is mounted directly on the airplane engine and the indicator is mounted on the instrument panel. The motor in the latter revolves an assembly of permanent magnets which imparts torque to an aluminum-alloy drag disk, thereby moving the indicator pointer over the scale until an equal and opposite restraining torque is developed in the control spring.[1] The generators and indicators are interchangeable with other instruments of the same manufacture and similar units made by other concerns.

During the past three years several new requirements have influenced the design and manufacture of this aircraft tachometer equipment: the operating temperature range has increased by nearly 50 per cent; the vibration conditions which these devices must withstand have become more severe with the production of faster and more powerful engines; and increased instrumentation has made better utilization of panel space essential. Revisions in generator and indicator design have resulted from the new temperature and vibration requirements. A new dual-element tachometer, occupying the space as one single indicator, has been developed to save panel area.

Generators

A cut-away view of a tachometer generator is illustrated in Figure 3; this readily illustrates the simple, sturdy construction of the generator. To obtain satisfactory operation at temperatures down to −65 degrees centigrade, a special low-temperature lubricant is now used in the ball bearings. The resulting torque required to drive the generator at −65 degrees centigrade is shown in Figure 4 for single- and double-element indicator loads.

With increased speed and power output of aircraft engines, the generator must withstand more severe vibration than ever previously encountered; and modifications in design now eliminate consequent hazards. The possibilities of lead breakage are eliminated by more secure clamping of leads; oil leakage from the engine into the generator winding is avoided by better oil seals and by additional vent-holes in the end-shield, preventing the build-up of oil pressure in front of the ball bearing at the flange-mounted end of the generator. Increased strength of the front end shield is assured by additional ribs, and the former two-piece receptacle end-shield is now a stronger and simpler one-piece casting.

The tachometer generator drive key is required to withstand accelerations of 400 revolutions per second per second. Generators of the present construction have withstood repeated accelerations as great as 800 revolutions per second per second without damage. In certain installations where unusually severe pulsations of the driving system are present, the drive-key design is further modified to prevent excessive generator wear and resulting pointer fluctuations in the indicator. This drive key includes a short section of flexible tachometer cable. The square driving tang is split diagonally through the center line and the two sections are spread so that no play is present between the drive key and the mating part on the engine. By this change in construction no indicator pointer fluctuation occurs after many hours' operation where previously the indication became unsatisfactory during the first 10 to 20 minutes of use.

Representative generator-voltage-output–speed curves are shown by Figure 5 for conditions of no load, one and two indicator element loads.

Indicators

The range of operating temperature for tachometer indicators has increased, upward from +45 degrees centigrade to +70 degrees centigrade, and downward from −35 degrees centigrade to −55 degrees centigrade. This increase in range

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Figure 1. Tachometer equipment

Left to right: Tachometer generator; single-element indicator, $3^1/_2$ revolutions; dual-element indicator; single-element indicator (330 degrees); synchroscope

from a total of 80 to a total of 120 centigrade degrees requires improved temperature compensation material so that the error in indication is not excessive.

Improvements in commercially available temperature-sensitive nickel-steel compensator material provide the typical temperature compensation curve shown in Figure 6; the uncompensated curve shows the change in indication (at the 3,000-rpm point) before the addition of compensator material, and the compensated curve shows that this error is reduced to less than one per cent by proper compensation.

Due to the high-ambient-temperature operation, it is essential that the lubricant for the indicator motor bearings have a low evaporation rate. To meet this requirement the indicator ball bearings are lubricated with inhibited blackfish jaw oil applied in controlled quantities. With this lubrication individual indicators have operated continuously for as much as 20,000 hours.

Room - temperature torque – speed curves for representative tachometer indicator motors are shown in Figure 7. The starting or pull-in torque is developed jointly by a permanent-magnet rotor and eddy-current hysteresis disk.

The vibration test for tachometer indicators consists of movement of the indicator on a 0.018–0.020-inch-diameter circle in a plane inclined 45 degrees to the horizontal. The top frequency vibration has been increased from 2,500 to 3,000 cycles per minute. All indicators are subjected to this vibration test after assembly to assure freedom from excessive pointer oscillations or changes in indication.

Dual-Element Indicator

As airplanes increased in size and complexity, the available panel space has been needed for more and more indications; thus, where previously a single-element indicator was installed it has become essential to build two or more indicators in one case wherever possible. This need leads to the development of the dual-element tachometer indicator, shown in Figure 1, to show the speed of two engines in the same panel space as was previously required for one engine. A cut-away view of this dual indicator, with one element removed, is shown in Figure 8.

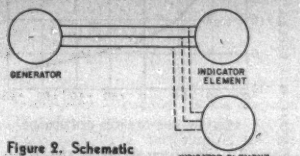

Figure 2. Schematic connection diagram

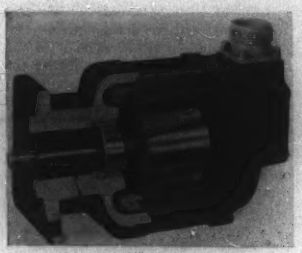

Figure 3. Cut-away view of generator

The dual indicator presented problems of much smaller-size motors, smaller rotating-magnet assemblies, and a means of coupling the two elements to a concentric pointer assembly. Previous experience with the single-element indicator showed the following adjustments to be desirable:

(*a*). Zero adjustment.

(*b*). Full-scale adjustment.

(*c*). Balancing means.

(*d*). Adjustable temperature compensation.

In addition cam adjustment of gear mesh has been built into each element of the dual indicator to facilitate adjustment and maintenance.

A special feature of the design is the possibility of disassembly into interchangeable subassemblies. These subassemblies may be adjusted, tested, and inspected as units and subsequently assembled into completed tachometers. The motor and magnetic-drag assembly are completely assembled and tested in the normal manufacturing procedure, thereby preventing expensive tear-downs at later positions. Field maintenance and handling is greatly facilitated by these types of construction.

Smaller Motor

For the synchronous motor of the dual indicator, a recently developed magnetic material, copper-nickel-cobalt, is used for the permanent-magnet rotor instead of the sintered-oxide material utilized in the single-element indicator. The new material offers the advantages of improved mechanical strength, greater ease of fabrication, and simpler assembly.

The stator of the indicator motor is of the conventional three-phase type. To decrease the temperature rise of the windings through greater thermal conductivity, glass-cloth slot insulation replaces the fiber type common to the single-element indicator. This change reduces the temperature rise by approximately ten per cent.

Drag Magnet Assembly

The necessity of providing two indicator elements in the space previously occupied by one necessitates smaller rotating magnets. In order to obtain sufficient torque for the moving element assembly, a second new magnet material is utilized. This material, Alnico V, produces approximately twice the external energy per unit volume of Alnico II used in the single-element indicator. Major differences in handling the two types of Alnico in manufacturing are the necessity for initial magnetization of the Alnico V during cooling from a semi-molten state, and the requirement that Alnico V be carried through a much greater temperature stabilization cycle than for Alnico II in order to prevent sub-

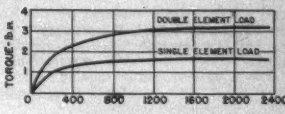

Figure 4. Generator driving torque at −65 degrees centigrade

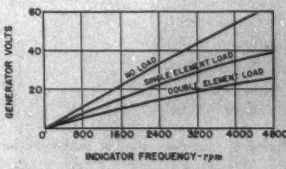

Figure 5. Generator voltage output

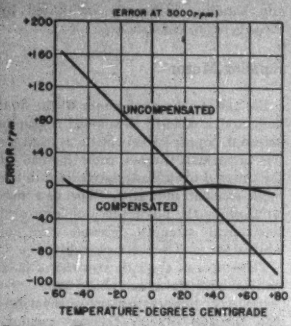

Figure 6. Typical temperature compensation

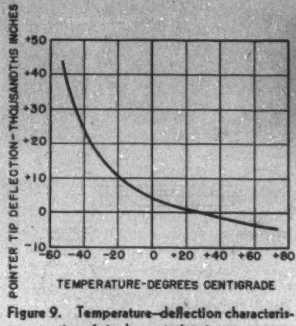

Figure 9. Temperature–deflection characteristics of single-coated pointers

Figure 10. Dual tachometers for supercharger and helicopter applications

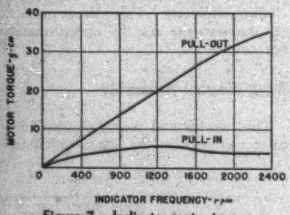

Figure 7. Indicator-motor torque

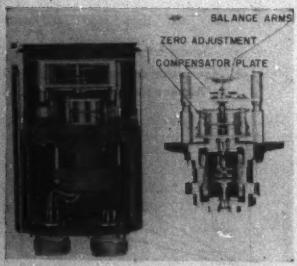

Figure 8. Cut-away view of dual indicator

sequent changes in magnetic strength throughout the instrument operating temperature range of −55 to +70 degrees centigrade.[2,3]

Calibration adjustment of the indicator may be accomplished either by magnetic knockdown with an a-c coil or by varying the gap between the two sets of magnets. The latter adjustment is normally used for only small changes in calibration and is readily made with the instrument cover removed. Calibration adjustment with a demagnetizing coil may be made to either element of the assembled indicator without affecting the calibration of the other element, although the magnets in the two assemblies are separated by less than three quarters of an inch. This method is ideal since the element being adjusted may be in operation while the demagnetizing is being done. Temperature compensation adjustment is provided by movement of the compensator plate (Figure 8) along the length of the magnets in order to shunt more or less flux.

Moving Elements

The zero-adjusting arm and balance arms are readily discernible in Figure 8. The mechanical assembly of gear hubs to shafts as small as 0.031 inch in diameter is accomplished by means of a knurl on the shaft; thus assuring a tight, permanent fit.

The concentric pointer shaft assembly (Figure 8) is supported at the ends by ring-stone jewels. Intermediate supports are provided by two additional ring-stone jewels mounted in the outer bearing sleeve with the first one supporting the front end of the inner shaft and the second the back end of the outer sleeve. The advantages of this assembly are its inherent line-up and a single end-play adjustment for the complete subassembly.

Prior to the increase in range of temperature operation, tachometer pointers were normally flat and painted with luminescent material on one side only. Changes in temperature cause bending of the pointer because of the difference in expansion and contraction of the aluminum pointer material and the fluorescent material. The amount of deflection occurring for a 0.010-inch-thick pointer $1^3/_{16}$ inches in length is shown in Figure 9. In order to improve this condition the pointer for the single-element indicator has been "ribbed" to reduce this bending action to less than half of its former value. Because of the small space between the two pointers on the dual element indicator, its pointers are made flat but are painted on both front and back sides, thus eliminating virtually all deflection.

Conclusion

The several problems of increased temperature range, additional vibration, and superior panel utilization have been met. Existing designs have been improved and new designs developed to accomplish the stringent wartime requirements.

In addition to the furthered development in magnetic materials and processes fostered by the designing of the tachometer equipment, certain unique applications have been made. Among the present and future applications are included airplane supercharger and helicopter rotor speed indication (Figure 10), test panel equipment, regulator control, and timing apparatus. A single indicator element from the dual tachometer can be built into a $1^7/_8$-inch diameter case for use where reduced size is paramount, and the separate indication of engine speed is desired.

By means of these design revisions it has been possible to meet the new requirements which aircraft tachometer systems have encountered.

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Automatic Control and Switching Equipment for Capacitor Banks and Its Application

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THE increasing use by utilities or industrial plants of shunt capacitors for voltage improvement, power-factor correction, and release of circuit capacity is leading in many cases to the desirability of automatically switching or controlling the capacitors.

On some utility and industrial system circuits, capacitors have been or are being applied to the extent that it becomes desirable to switch part of them at time of light load to control voltage and to minimize circuit losses.

Recent studies[1] have shown that as systems grow, capacitors on distribution feeders and in substation banks have a definite place in the growth process. There should be, therefore, an increasing demand for automatic control equipment in this connection. Where industrial plants are encouraged, by means of the power-factor clause in the utility rate structure, to supply part of their own magnetizing kilovars, it sometimes may be desirable to switch the capacitors. This paper offers application information as a guide to the selection of proper automatic switching equipment, and describes available types of control equipment.

Reasons for Switching Capacitors Automatically

Capacitors applied for voltage-regulation purposes should be automatically controlled where manual switching is not convenient or reliable. Switching also may be necessary or desirable to avoid overvoltage or excessive losses, particularly during light-load periods for capacitors used to reduce circuit loadings, or to meet the requirements of the power-factor clause of an electric-power rate.

Switching usually need not be considered if the minimum-load kilovars exceed the capacitor kilovolt-amperes. It is shown in the appendix that circuit losses will be a minimum if the unswitched capacitor kilovolt-amperes equals the average kilovar requirement of the load, that is, the average ordinate of the daily kilovar-load pattern. In some cases automatic switching equipment cannot be justified economically if losses are the only consideration.

Types of Equipment

In addition to the capacitors, automatically controlled capacitor equipment consists of:

A. Switching device. For convenience, this may be divided into the following classes of application:

1. Low-voltage circuits (600 volts or less)
2. Medium-voltage circuits (2,400 to 13,800 volts)
3. Utility distribution feeder circuits.

B. Control equipment for automatically controlling the switching device associated with the block of capacitors.

Main Switching Device

1. Switching Equipment for Low-Voltage Circuits. This voltage class (up to 600 volts) is encountered most generally in industrial plants, with the nominal 460-volt circuit being most common. The two types of equipments for this service are air circuit breakers and contactors.

Standard air circuit breakers generally are used, and have the advantage of providing fault protection in addition to the switching function. Breakers are not designed for highly repetitive operation, but in the average industrial plant the number of operations is not large enough to result in a serious maintenance problem. In those installations where the number of operations is large, contactors are the logical selection and are available with or without fuses.

2. Switching Equipment for Medium-Voltage Circuits. Standard power circuit breakers are used almost always as the switching device for power circuits in the voltage range of 2,400 to 13,800 volts. Contactors are available for 2,400- and 4,160-volt service.

3. Switching Equipment for Use With Utility Distribution Circuits. This class of switching equipment is limited almost entirely to the utility field for use with small banks of capacitors in which the switching device is primarily a switch only and not a breaker; fault protection is provided by other means. Here a power breaker could not be justified economically for the small capacitor banks (45 to 180 kva) located on distribution circuits. Oil switches for pole mounting are available for this service in ratings up to 100 amperes and 5,000 volts. A typical unit-type equipment, including capacitors, switch, and control for a 180-kva bank is shown in Figure 1.

Automatic Control Equipment

The control is the heart of the equipment; it receives the signal, interprets it, and then sets into operation the proper devices to perform the desired function. This control consists fundamentally of the following:

1. Master Element. This is the "brain," and may be a voltage-, current-, kilovar-, or power-factor-sensitive device.

2. Time-Delay Device. A time-delay device is a practical necessity to avoid unnecessary operation of the switching device for signal changes that are only momentary. This may be a separate device or may be incorporated as part of the master element.

3. Sequencing Device. This is necessary only for multistep control, and determines the order in which the capacitor groups are switched in and out of service.

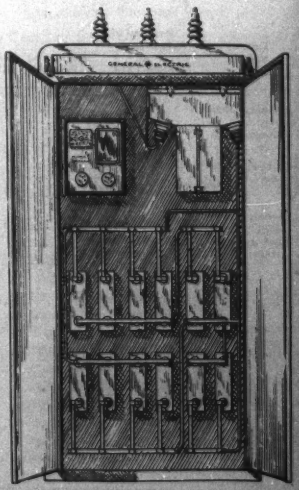

Figure 1. Unit-type pole- or base-mounted automatically controlled capacitor equipment, 180 kva, 2,400 volts

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4. Miscellaneous Relays or Devices. A lockout device is required to prevent the switching device from reclosing on a fault. It is also common to include, for convenience of control, an "automatic–manual" transfer switch and a "close–trip" switch for each capacitor block.

Control power is standardized at 220 volts alternating current or 125 volts direct current, following switchgear and control practice.

The simplified control schemes for the two most common controls are shown in Figures 2 and 3. To illustrate the function of each of the component parts, the detailed performance of a typical control will be outlined. The sequence for a single-step voltage-sensitive control is quite straightforward and will not be discussed. It should be noted that, in accordance with standard practice, the devices are shown in their de-energized position.

Figure 3 shows the schematic diagram and Figure 4 a control panel for a three-step kilovar control. The sequence of operation is as follows: As the load magnetizing kilovars increase and reach a predetermined value, the master element operates, initiating the time-delay device and establishing a closing circuit for the correct direction of the sequencing switch. If, after a preset time delay, the master element still indicates capacitors are needed (that is, the signal was not the result of just a momentary disturbance), the time-delay device operates and starts the sequencing device. Once the sequencing device is started its motor continues to operate until the first position is reached, when a set of contacts closes to initiate the closing circuit of the switching device. The same control-sequence procedure is followed for switching in successive blocks. When the load kilovar requirements decrease, the capacitors are switched out of service in the opposite sequence, that is, the last capacitor group switched into service is the first group switched out of service.

If the signal to the master element does not last for the full time-delay period, the control is arranged so the timing device will be reset for a full timing period for its next operation.

Master Control Elements

There are two characteristics common to all regulating types of master elements that should be fully understood to select intelligently the proper device. These are the range of adjustment and the band width.

The range of adjustment refers to the normal operating level of the device, and is necessary, for practical purposes, to allow for differences in operating conditions. For example, the system voltage level may vary over a rather broad range, so the normal setting of a voltage-sensitive device must be capable of adjustment.

Band width is defined as the difference between pickup (switching a capacitor on) and dropout (switching a capacitor off). *The band width must be larger than the change in signal caused by switching the largest block of capacitors to prevent pumping action of the control and switching equipment.*

The most common types of master-control elements are:

(*a*). Voltage.
(*b*). Current.
(*c*). Kilovar.
(*d*). Power factor.
(*e*). Time switch.

(*a*). *Voltage-Sensitive Device.* This is essentially a contact-making voltmeter; the most common type is that used with voltage regulators. Standard voltage-sensitive devices are available with a range of adjustment from 90 to 110 per cent, and with a band width adjustable from three to seven and a half per cent. A multistep control requires the lower band width, as it is likely to be used for a regulating duty where fine control is necessary.

Table I. Application of Automatic Capacitor Switching Control

Type of Master Element	Switching Function: Removal of Capacitors at Light Load	Regulating Voltage	Regulating Kilovars	Switching Capacitors on Basis of Power-Factor Clause Requirements* Power Factor for Billing Determined By: Average Monthly Power Factor: Occasional Measurements	Average Monthly Power Factor: Continuous Measurements	Average Monthly Power Factor: Kwhr and Kvarhr Comparison	Power Factor at Maximum Kw Demand: Occasional Measurement**	Power Factor at Maximum Kw Demand: Continuous Measurement of Power Factor	Power Factor at Maximum Kw Demand: Kwhr and Kvarhr Comparison	Power Factor at Maximum Kw Demand: Billing on Kw and Kvar Demand	Power Factor at Maximum Kw Demand: Billing on Kva Demand
Voltage, single-step	O.K.				Leave capacitors unswitched	Leave capacitors unswitched					
Voltage, multi-step	Usually not necessary	O.K.									
Current, single-step	O.K. if power factor versus load characteristic known										
Current, multi-step											
Kilovar, single-step	O.K. where voltage magnitude not satisfactory signal			O.K.			O.K.	O.K.	O.K.	O.K.	O.K.
Kilovar, multi-step	Usually not necessary		O.K.	O.K. where graded control desired			O.K. where graded control desired →				
Power factor, single-step				O.K. but desensitizing control required			O.K. but desensitizing control required →				
Power factor, multistep				O.K. where graded control desired but desensitizing control required			O.K. where graded control desired but desensitizing control required				

* Where capacitors are used for rate purposes only, they need not be switched unless there is a penalty for leading power factor. It may be desirable to switch capacitors at reduced loads to prevent excess voltage and losses

** At or near maximum load.

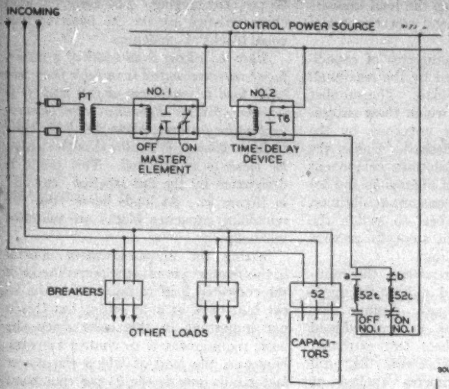


Figure 2. Simplified schematic connection diagram showing single-step voltage control

Devices:
1—Master element
2—Time-delay device
52—Capacitor switching device (breaker)
PT—Potential transformer

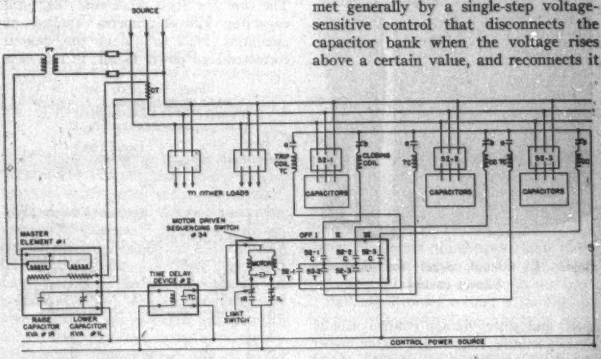
(*b*). *Current-Sensitive Device.* This is essentially a contact-making ammeter, and since this type of control is more likely to be for an ON–OFF than for a regulating function, it usually is furnished in a single-step control. The standard range of adjustment is 25 to 100 per cent of the coil rating (five amperes).

(*c*). *Kilovar-Sensitive Device.* A kilovar-sensitive device may be thought of as a contact-making wattmeter connected to read kilovars; usually it is an induction-type directional relay for single-phase indication. It is customary to use two master elements for multistep control in order to provide a simple and convenient means for adjusting the band width. One master element can be used for single-step control, and a suitable band width can be obtained by a recalibrating device.

The characteristics of the kilovar or reactive-ampere master elements commonly are given in terms of reactive amperes referred to the secondary side of the current transformer (five amperes normal). A useful range of adjustment is 3.3 amperes (66 per cent) lagging to 1.6 amperes (32 per cent) leading, with a band width adjustable from 2.5 to 0.7 amperes (50 to 14 per cent).

(*d*). *Power-Factor Device.* Since power factor is the measure of an angle, the usual power-factor or angle-measuring devices are suitable for this purpose. What has been said regarding the kilovar-sensitive master element also applies generally to a power-factor-sensitive master element. It is usually an induction type directional relay.

Since the band width in *kilovars* of a power-factor control is variable and changes uniformly with kilowatt load, and because at light load the band width may be smaller than the change in signal caused by switching the largest block of capacitors, some form of desensitizing control is necessary to prevent a pumping action at light loads.



(*e*). *Time-Switch Device.* This is a simple control device used for switching capacitors at a predetermined time, and is used on some utility feeder circuits where the load characteristics with time are reasonably constant.

Time-Delay Device

A time-delay device may consist of an electronic or motor-driven timer. Usually, only one time-delay device is used, regardless of the number of steps. If, however, a different time-delay is required for the two sequences, two devices are required. The amount of time-delay is not critical, and is set long enough to avoid unnecessary operation because of momentary circuit disturbances. Range of adjustment is desirable; accuracy in timing is not of extreme importance. Practical experience has indicated that the range of adjustment is from 5 to 20 seconds.

Sequencing Device

A sequencing device is used only for multistep control, and consists of an arrangement of interlocked relays or a motor-driven cam switch.

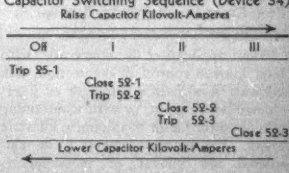
The interlocked-relay scheme is simple, and can be used for two-step control. For a larger number of steps, the motor-driven sequencing switch is simpler and less expensive, and also has the advantage that additional steps of control may be obtained conveniently by adding additional contact positions on the switch. With the interlocked-relay scheme, a major change in wiring and arrangement is required to increase the number of steps.

General Application of Automatic Control Equipment*

For Removal of Capacitors at Light Loads to Reduce Voltage and Losses

In many cases this will be the only switching requirement, and it may be met generally by a single-step voltage-sensitive control that disconnects the capacitor bank when the voltage rises above a certain value, and reconnects it

Figure 3. Simplified schematic connection diagram showing three-step kilovar control



when the voltage falls below a predetermined value.

If the supply-system voltage is subject to variations independent of variations in the load with which the capacitor bank is associated, the voltage-sensitive control may cause the bank to be switched somewhat independently of the load. For example, in some cases the capacitors may be switched off during peak load, or, switched on during light load, with resultant feeder overload or undue losses. This can be obviated by the use of a kilovar or, in some cases, a current-sensitive control.

The inherent characteristic of the

*A discussion of the application suggestions summarized in Table I.

power-factor-sensitive control requiring it to be desensitized at light load to prevent hunting precludes its use for the application considered in this section.

For Voltage Control

If voltage control is the primary objective, a voltage-sensitive control will be

Figure 4. Control panel for three-step kilovar control

used, and since voltage control usually implies holding the voltage within rather close limits, a multistep control should be used. The capacitor kilovolt-amperes per step should be co-ordinated properly with the voltage band width.

For Kilovar or Power-Factor Control*

This application is concerned with bulk kilovar control in connection with kilowatt flow past a purchase or interchange power point, or with maintaining a high power factor to minimize kilowatt losses. The master elements to be considered are kilovar or power-factor-sensitive devices.

In power-dispatching work, the two-quantity concept, which treats kilowatts and kilovars as two separate and independent quantities, is gaining increasingly greater favor. In instances where this concept is adhered to, switching the capacitors as a function of kilovars doubtless will be the predominant approach.

To compare the relative merits of a kilovar-sensitive and a power-factor-sensitive master element where the prime objective is to control the flow of kilovars to a large load, refer to Figure 5. Part (a) shows the circuit involved, with a multistep capacitor bank installed near the load for supplying the load kilovars to maintain a peak load power factor of 95 per cent.

The total kilovolt-amperes of capacitors needed is dictated by the maximum requirements of the load. The number and size of steps in which these capacitors are switched is governed by the fineness of control desired. Unless the kilovar versus the kilowatt component of load (the line *a–b* of Figures 5b and 5c) is known to be fairly constant at all times, it probably will be best to switch the capacitors in uniform steps to prevent the possibility of hunting.

Let the line *o–a* represent the minimum uncorrected load and *o–b* the maximum uncorrected load. Assume line *a–b* to represent the uncorrected-load variation between these two extremes. The line *b–c* then represents the total capacitor kilovolt-amperes applied at maximum load to obtain the desired corrected-load power factor, in this case

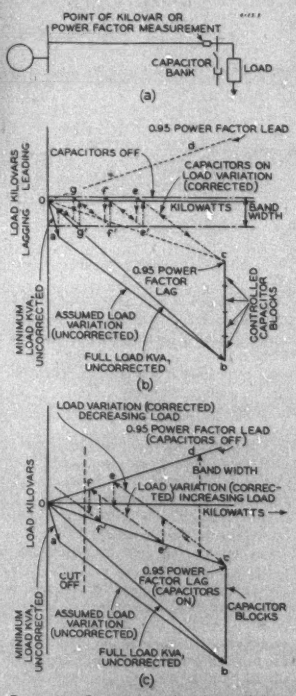


Figure 5. Comparison of multistep kilovar- and power-factor-sensitive control used to switch capacitors automatically for regulating kilovars

(a). One-line circuit diagram
(b). Performance diagram with kilovar control
(c). Performance diagram with power-factor control

95 per cent lagging. The corrected-load characteristics are on the basis of four equal blocks of capacitors.

Since the kilovar band width of a power-factor-sensitive control is variable from zero at no load to maximum at full load, it is necessary that the automatic control be made inoperative for loads below which the band width in kilovars is smaller than the capacitor block to be switched. This point is designated by the line labelled "cut off" in Figure 5c. At loads below this, the remaining capacitor blocks are switched manually.

Setting the kilovar-sensitive control in this manner permits the power factor of the corrected load to fall outside the 95 per cent band at light loads; but this is not important in this case, since the basic requirement is to control kilovars. However, the load at which the power factor falls outside the 95 per cent band may be reduced considerably by raising the operating band of the control vertically and sacrificing the very low leading kilovar characteristic. This load can be reduced still further by use of smaller switched blocks.

It will be noted from the uncorrected-load characteristic and the size of capacitor blocks shown in Figure 5c that, if a power-factor control is used, the automatic switching will be done on only two steps instead of the desired four steps as shown. If, for this reason, switching in fewer and larger steps is considered, the "cut off" point will occur at a higher load; this will mean a smaller operating region in which the automatic control is effective.

It can be seen from a comparison of Figures 5b and 5c that a kilovar-sensitive control set for low lagging kilovars and very low leading kilovars will provide a more constant value of kilovars at all loads than does the power-factor-sensitive control. The low leading kilovar feature may be of particular value in this case if it is not desirable to have kilovars flow from load to the power source. A power-factor control entails complications if power flow may be in either direction past the control point.

For Meeting the Requirements of the Power-Factor Clause of an Electric-Power Rate

If capacitors are applied for rate purposes only, and voltage rise and losses at light load are not a problem, it is not necessary to switch the capacitors unless there is a penalty for leading power factor.

If load power factor is determined on an average monthly basis by continuous measurement or by an integration of the kilowatts and the kilovars for the month, it will be advantageous to the consumer to leave his capacitors connected at all times if possible. Otherwise, generally speaking, they can be off except during the period of maximum demand, or during

* Exclusive of that for rate-clause purposes.

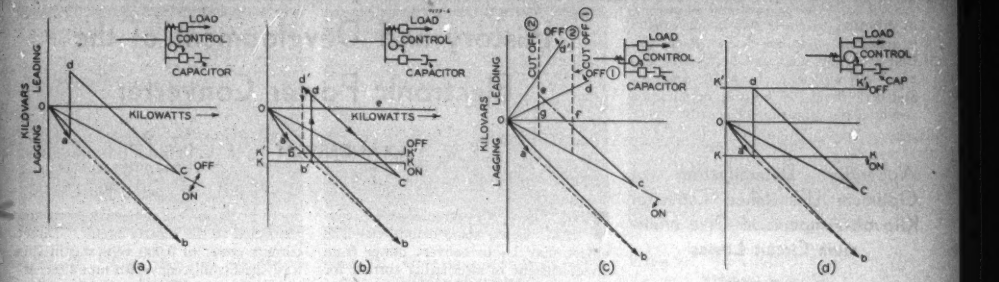


Figure 6. Comparison of single-step kilovar- and power-factor-sensitive control used to switch capacitors applied on behalf of rates

(a). Single-step power-factor control measuring uncorrected load

(b). Single-step kilovar control measuring uncorrected load

(c). Single-step power-factor control measuring corrected load

(d). Single-step kilovar control measuring corrected load

a period of relatively heavy load (not necessarily maximum demand) when the "occasional" measurement is apt to be made.

Where it is desired to have the capacitors on at heavy loads for rate reasons, but off at light load to minimize voltage rise or losses, the kilovar or power-factor master element will provide the most direct solution of the control problem. Unless multistep switching and control to regulate voltage or to keep the losses at a minimum can be justified, a single-step control, judiciously set, will be sufficient.

Figure 6 shows a comparison of the single-step kilovar and power-factor control used primarily in conjunction with a rate clause. The diagrams plot uncorrected and corrected kilovars versus load kilowatts. In all cases a light-load kilovolt-ampere *o–a* and a maximum-load kilovolt-ampere *o–b* is considered, with a straight-line variation between these limits for simplicity. Assume it is desired to hold a power factor at peak load as represented by the line *o–c*. A single-step power-factor control viewing the *uncorrected-load power factor*, as in Figure 6a, switches the capacitors on for load power factors below *o–c* and switches them off for load power factors above *o–c*. (Actually, to avoid unnecessary operation, this type of control would have a band width of a few degrees, but this is neglected in this analysis.) For the load pattern shown, the capacitors are on even at light load, with a resultant leading kilovar component corresponding to point *d*. As the locus of the uncorrected-load kilovolt-amperes proceeds along the assumed pattern *a–b*, the locus of the corrected pattern follows *d–c*. Therefore, for this load pattern, the capacitors are never off and the power factor is unnecessarily high at light load.

If the power-factor control measures the *corrected power factor* as shown in Figure 6c, the ON and OFF characteristics would result in a band width varying with the kilowatt load. However, an auxiliary control device operable at point *f* is necessary to prevent the possibility of hunting. The load range of operation of the control could be increased somewhat by moving the OFF characteristic to *d'*, but this scheme has the disadvantage of the complication interposed by the desensitizing relay and its adjustment.

The kilovar control element measuring *uncorrected kilovars*, Figure 6b, has an operating characteristic *kk* and *k'k'* (OFF and ON again differing practically by a small band width). The relay pickup is set somewhat above the corrected kilovar component of the expected peak load to assure the capacitors being on at heavy loads which are not necessarily up to the expected peak. As the uncorrected load increases, the capacitors go on at *b'*, making the corrected load *o–d*. At peak load the corrected kilovolt-amperes are *o–c* and, as the uncorrected load decreases to *o–b''*, the capacitors are switched off.

If the single-step kilovar control is connected to view *corrected kilovars*, the performance is as shown in Figure 6d. Note that the band width must be widened to exceed slightly the capacitor-bank kilovolt-amperes.

It has been pointed out previously that if multistep switching is used for rate purposes, it probably will be for voltage regulation and to minimize losses. With this objective, it is considered that multistep kilovar control will provide the best results more simply than a power-factor-sensitive control as may be appreciated from a study of Figure 5.

Factors Influencing Operation of Control Equipment

Size and Number of Capacitor Groups

The type of automatic control for capacitor switching is independent of the kilovolt-amperes and voltage rating of capacitor blocks. The rating of a block and the number of blocks in a bank is determined by load requirements and the fineness of control desired. It usually is best to switch in blocks of equal rating, unless the daily kilowatt-versus-kilovar pattern of the load is definitely known and known to be the same from day to day.

Point of Signal Measurement

Voltage Control. When automatic capacitor switching is done in response to voltage, the master-control element should obtain its signal from the point at which voltage is to be controlled. Where capacitors are located on feeders supplied from a common bus, with the bus in turn supplied from a system of limited capacity such that switching the feeder capacitors causes appreciable voltage change at the bus, the signal for switching should be taken from the bus. If individual feeder voltage control is attempted, the bus-voltage variation as a result of switching one of the feeder capacitors may require the switching of other feeder capacitors, with a resultant hunting action of the controls.

Current Control. The single-step current control may measure the uncorrected-load current for simplicity. The multiple-step current control should receive its signal from the uncorrected-load current to prevent false operation, and this requires a separate master element for each step, or a recalibration for each step if only one master element is used.

Kilovar or Power-Factor Control. Individual cases will determine whether corrected or uncorrected load should be used as a signal for single-step control (see Figure 6). A multistep control should measure the corrected load to assure proper operation, regardless of possible variation in load characteristics.

Desensitizing Requirement of Power-Factor Control

It has been shown previously that in most cases the power factor type of control should be made inoperative at low load to prevent the possibility of hunting action. To preclude all possibility of such hunting, the "cut off" or desensitizing operation should occur at some predetermined value of kilowatts; thus the need for a contact-making wattmeter

in addition to the power-factor control is indicated. In some cases it is possible that a current relay can be used to provide "cut off" with reasonable accuracy and little danger of hunting or pumping action of the power-factor control.

Appendix. Determination of Optimum Unswitched Capacitor Kilovolt-Amperes to Give Minimum Circuit Losses

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Figure 7 shows the variable portion of the daily kilovar load pattern of a circuit. Let I_c represent the unswitched capacitor

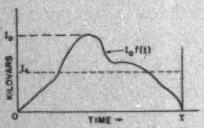

Figure 7. Daily kilovar load pattern of a circuit

kilovars or current. The square of the rms corrected current in the circuit is given by

$$(I_{rms})^2 = \frac{1}{T}\int_0^T \{I_0 f(t) - I_c\}^2 dt =$$

$$I_c^2 + \frac{1}{T}\int_0^T \{I_0 f(t)\}^2 dt - \frac{2}{T} I_c I_0 \int_0^T f(t)dt \qquad (1)$$

Differentiate equation 1 with respect to I_c, equate to zero, and solve for value of I_c to minimize the loss, and obtain

$$\frac{d(I_{rms})^2}{dI_c} = 2I_0 - \frac{2I_0}{T}\int_0^T f(t)dt = 0 \qquad (2)$$

or

$$I_c = \frac{I_0}{T}\int_0^T f(t)dt \qquad (3)$$

$I_0 \int_0^T f(t)dt$ = area of the load pattern,

and when divided by T minus the width, the average ordinate is obtained. Hence, for *any* kilovar pattern, the minimum circuit loss with a fixed kilovar supply is obtained by using a value of I_c equal to the *average* value of the requirement.

Reference

1. THE EFFECT OF KILOVAR SUPPLY ON THE DESIGN OF SYSTEMS FOR LOAD GROWTH, T. W. Schroeder, J. W. Butler, N. H. Meyers. ELECTRICAL ENGINEERING, volume 63, February 1944, pages 69–76.

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History and Development of the Electronic Power Converter

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THE TERM "electronic power converter" needs some definition. The object may be to convert power from direct current to alternating current for d-c power transmission, or to convert power from one frequency into another, or to serve as a commutator for operating an a-c motor at variable speed, or for transforming high-voltage direct current into low-voltage direct current. Other objectives may be mentioned. It is thus evidently not the objective but the means which characterizes the electronic power converter. Other names have been used tentatively but have not been accepted. The emphasis is on electronic means and the term is limited to conversion of power as distinguished from electric energy for purposes of communication. Thus the name is a definition.

History

Within the scope of the definition a mercury-arc rectifier is an electronic power converter. From this point of view we must trace its history back more than 40 years. In the first 20 years of this period the development was rather slow. An important discovery however was made by Langmuir in 1913 when he found that a negative electric potential introduced between the cathode and anode prevented the start of current flow through the anode.

At this time the initial development took place of the high-vacuum radio tube which was an evolution of the deForest audion. These tubes were soon used successfully at high voltages to convert direct current into alternating current of audio and radio frequencies and serious thought was given to their use for power conversion. The high internal voltage drop was however a serious obstacle. Attention therefore returned to the mercury arc and ten years after Langmuir's discovery, tests were made which proved that the mercury-arc rectifier could be inverted so as to convert direct current into alternating current. The tests were made with a standard high-voltage rectifier of the type used for series arc lighting. It had a bulbous head and two upturned side arms. Carbon electrodes were introduced at the elbows of the side arms and connected to the control circuit. Direct current power of 9,000 volts was in this way successfully converted into alternating current and then again into low-voltage direct current. A new electrical industry was immediately foreseen where power would be transmitted long distances by high-voltage direct current and railroads would be electrified by locomotives carrying electronic converters from a high-voltage d-c trolley to low-voltage d-c motors. After another 20 years this new industry is now well under way on a modest scale but comprising installations up to 20,000 kw.

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Evolution of the Electronic Converter

The first tests of the inverter were made with a mercury-pool tube and the latest installations have mercury-pool cathodes. Between these points there is, however, a significant development. The structure of the tube itself can assume a number of successful forms, such as the thyratron, the ignitron, and the excitron. But all these forms of tubes have certain characteristics in common which force the electrical engineer to accept a new point of view in the methods of its application. This has perhaps been the reason why the practical development has up to the present been rather slow. There has been an unwillingness to face the facts or what so far appear to be the facts, that high-voltage tubes are subject to momentary faults known as arc backs and loss of grid control. The hope that the tubes could be so improved that these faults could be eliminated has so far been wishful thinking. But a much more constructive point of view has been adopted which accepts the electronic faults as inevitable while measures are taken which render the faults perfectly harmless so long as the incidence of the faults is kept within reason. Installations of d-c power transmission and electronic frequency changers are at present operated on this principle with great success. Electronic

Figure 1. Electronic converter, dual-conversion type

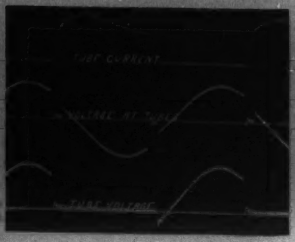


Figure 2a. Wave shapes of single-phase inverter

Figure 2b. Wave shape of six-phase inverter with low a-c reactance

Figure 2c. Wave shape of six-phase inverter with high a-c reactance

faults occur several times a day. They can, however, be observed only by delicate instruments and do not in any way interfere with power service.

Suppression of Electronic Faults

An electronic fault may or may not result in a short circuit, depending upon what means are used to suppress it. In low-voltage rectifier installations the faults occur so seldom that it has proved satisfactory to disconnect the fault by a high-speed circuit breaker. In high-voltage installations the faults occur so often that this would not be permissible because power delivery must be continuous. In the original installation of d-c power transmission for the New York Power and Light Corporation between Mechanicville and Schenectady, this situation was first met by the use of constant current as described in a paper in 1935 by Willis, Bedford, and Elder. In a constant-current system a momentary short circuit is of no significance. Such a system is therefore adapted to the characteristics of the electronic converter. Operation at constant current was successfully continued for four years but when plans were made for future installations it was found that the constant-current system was not well adapted to existing practice of power distribution. The reactance–capacity networks used for conversion between constant current and constant potential were therefore removed and the system has been operating at constant potential for several years. In this connection new means were developed for suppressing the electronic faults. These methods have proved entirely successful and have been adopted in later installations. The sequence of events is illustrated by oscillograms taken during practical operation. Samples of these oscillograms are shown herewith.

Figure 1 shows a simplified diagram of an electronic converter of this type used for d-c transmission and frequency conversion. It should be noted that the power circuits of the rectifier and the inverter are identical and that it is the grid control which makes one part of the whole into a rectifier and the other into an inverter. By change of the grid controls, the power flow can be reversed. The rectifier and the inverter are however not independent devices like a generator and a motor but function together as a whole —the electronic converter. Electronic faults which occur in the inverter are suppressed by the rectifier. The rectifier suppresses its own faults but even this statement must be accepted with some qualifications. The rectifier can suppress its own faults because the inverter cannot feed current back into the rectifier but if several rectifiers feed the same circuit in multiple they can feed current into each other's faults and therefore fault suppression depends upon interaction between the several rectifiers.

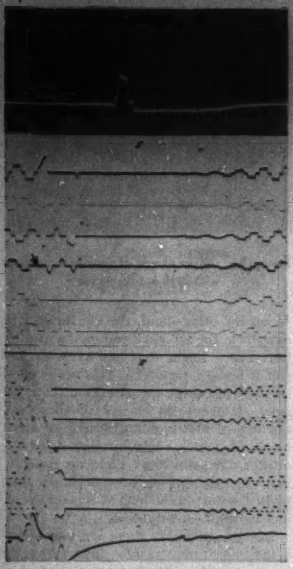
The oscillograms of Figure 2 show a typical performance of a single-phase and a six-phase inverter. The rather complicated wave shapes of the six-phase inverter can be easier understood if the records of the single-phase inverter are examined first. The three recorded curves represent the wave shapes of the current in the a-c line, the voltage between a-c lines, and the voltage between cathode and anode of one tube. The commutation period is marked by the abrupt depression of the alternating voltage near the end of each half cycle. The brief recovery of the voltage before it passes through zero is the margin of commutation. This same margin is also indicated by the brief negative swing of the voltage between cathode and anode. If the load is increased to the point where this margin is used up, the inverter goes into short circuit. With this in mind we can examine the six-phase wave shapes and interpret them as the composite of three single-phase wave shapes. Each phase wave shows its own commutation period and also secondary reactions from the commutation of the other phases.

The electronic fault may be of the nature of an arc back or a loss of grid control known as a "shoot-through." A simple arc-back has so little effect upon the operation of an inverter that it is difficult to discover whether it has taken place. It wipes out the negative voltage that marks the commutation margin but this in itself causes no disturbance. If, on the other hand, the ionization left over from the arc back causes the grid to lose control in the next half cycle the result is a shoot-through. This occurrence is, however, more the exception than the rule. It seems to be one of those sequences of events characteristic of electronic phenomena which follow a law of chance over which we have no control. But as engineers, we are not much disturbed about this so long as we can avoid any harmful consequences.

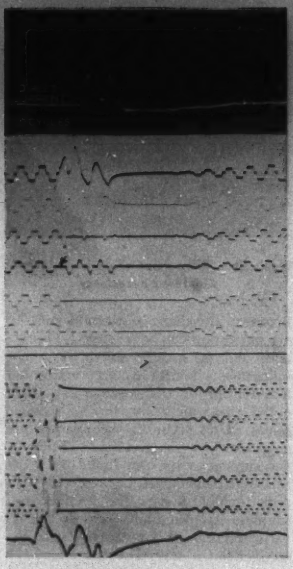
Besides arc backs there are two other causes which may initiate shoot-throughs in an inverter. These are not electronic faults in the same sense as arc backs, and there is a fair chance that they may be entirely eliminated. One of these causes which has been observed in our earliest installations is voltage transients of very short duration which make the grid momentarily positive at a time when it should be negative. Faults from this cause have been eliminated by the use of suitable filters. A third cause of faults is the occasional failure of an igniter to fire. This difficulty has not yet been entirely overcome but the rate of progress in this technique promises that it will eventually be entirely eliminated.

While thus some causes for faults are gradually being removed we must face the conclusion that shoot-throughs in high-voltage inverters will occur from time to time and we must be prepared to meet this situation in a practical way.

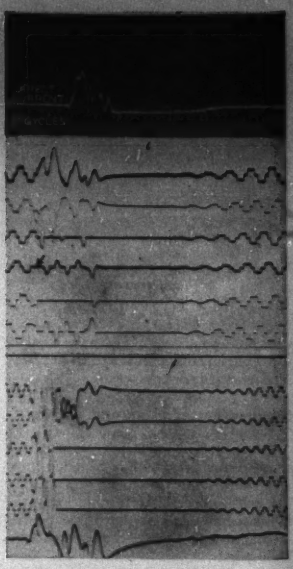
From this starting point there are several possibilities. The inverter may be adjusted so as to work with a good margin of commutation and the power supply may have a short-circuit current that does not greatly exceed the normal load current. In that case the inverter may have enough margin to commutate the increased current and the fault clears itself. It is then difficult to discover that it has occurred and the operator would seldom notice it. Faults which clear themselves are characteristic of circuits containing several rectifier and inverter units in series. It was the normal performance of a 24-phase developmental set tested a number of years ago with four rectifier units and four inverter units in series. This is worthy of note



A. Fault involving opposite inverter tubes in both inverters. Both coils of d-c reactor in. Bottom trace is secondary current of current transformer in direct current

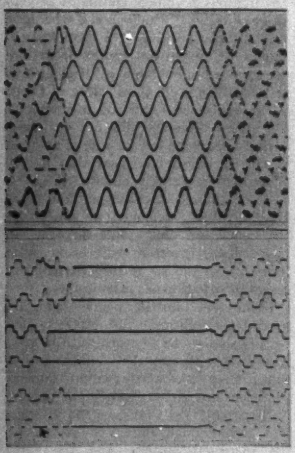


B. Fault including two legs of one inverter transformer. Both coils of d-c reactor in. Bottom trace is secondary current of current transformer in direct current



C. Fault including two legs of one inverter transformer and two legs of one rectifier transformer. Both coils of d-c reactor in. Bottom trace is secondary current of current transformer in direct current

Figure 3. Oscillograms of inverter faults. Arrows indicate made fault—igniter miss



D. Wave shapes of phase voltages and phase currents during faults

when we contemplate d-c power transmission at high voltages. Such installations will necessarily have many units in series and they can be so designed that electronic faults will clear themselves. Each unit in such a system operates at constant potential but an electronic fault in one tube does not disturb the sum of electromotive forces in the system enough to interfere with normal operation.

Returning to the sequence of events that may follow an electronic fault we may assume that in some cases the current which follows the fault is so high that the inverter cannot commutate it. This is the case in the d-c power transmission from Mechanicville to Schenectady and in the frequency changer described in companion papers. In these cases it is necessary to clear the fault by control of the rectifier. The oscillograms of Figure 3 show such a typical sequence. The sudden rise in current acts upon a fast relay controlling the igniter and grid circuit. Consequently the current which has been built up in the power circuit is no longer maintained by any electromotive force and decays at a rate dependent on the time constant of the circuit. It is important that the rectifier should not go into action again until the current has decayed to a value which the inverter can commutate. A time relay delays the action accordingly. In about one-fifth of a second the normal operation is resumed.

The Single-Conversion Frequency Changer

Another type of electronic converter is shown in Figure 4. It is the frequency changer used with the thyratron motor described in a paper by Alexanderson and Mittag in 1935. This electronic converter has not yet been given a name by which it can be readily identified. It is proposed here that it be known as the single-conversion frequency changer. The energy is converted by electronic means only once whereas in the dual-conversion type of frequency changer the power is first converted into direct current and then back to alternating current. Both function in the same way as a non-synchronous tie between two a-c systems. Besides this the single-conversion type has many desirable characteristics, such as being adapted to feed a stub-end load. The motor for which it was originally developed is a stub-end load and starts from standstill with a good torque like a d-c motor. The single motor may be replaced by a synchronous condenser and an independent distribution system including a multiplicity of motors.

The problem of suppressing electronic faults is solved in this type of electronic converter in a different way. When for one reason or another a loss of grid control occurs in one of the tubes the resulting disturbance lasts only one-half cycle because each tube is a rectifier as well as an inverter and the rectifier function commutates the fault current out of the tube where the fault occurred. The

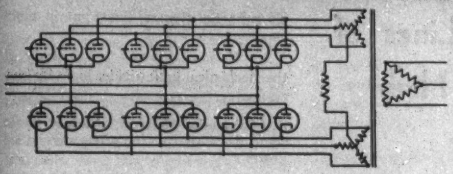
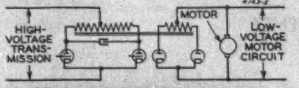


Figure 4 (left). Single-conversion-type frequency changer

Figure 5 (below). D-c transformer



practical result is that this type of electronic converter is entirely free from the problem known as shoot-through in the simple inverter. Thus it will continue to function with slightly reduced power even if several tubes are disconnected, whereas the simple inverter becomes inoperative if a single tube fails to function.

The D-C Transformer

One of the first objectives in the development of the inverter was to provide a way for transforming direct current from high voltage to low voltage. D-c transformation has not yet found application in any large scale. But the experience gained in d-c power transmission indicates that it is from a technical point of view entirely practical. The electronic industry is waiting for a demand where this experience can be applied. The questions that are likely to be asked are: How will it start? Will it require moving machinery? How will it ride through faults?

In order to give a practical answer to these questions, tests have been made represented by the diagram, Figure 5, and oscillograms, Figure 6. The power source is assumed to be a rectifier station like the one used in the d-c transmission from Mechanicville to Schenectady. The receiving station has no moving parts. It has a step-down transformer from the high-voltage inverter to the low-voltage rectifier. A capacitor is in shunt with the transformer. The load is a d-c motor. One oscillogram shows how the operation is initiated from a dead start by application of the grid control to the high-voltage inverter. A second oscillogram shows the characteristic wave shapes.

Figure 6a. Wave shapes of inverter in d-c transformer

Figure 6b. Wave shapes of rectifier in d-c transformer

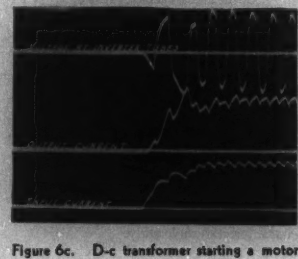


Figure 6c. D-c transformer starting a motor load

Adaptability of the Electronic Converter

Three types of electronic converters have so far been discussed and it has been shown how means have been provided for suppressing electronic faults. In practical operation there are also apt to be circuit faults. The d-c transmission line is for instance sometimes struck by lightning. The short circuit following a lightning stroke is cleared by the control system which is provided for suppressing electronic faults. The transmission line is therefore immune to lightning strokes so long as permanent damage is not done to the insulators. In the design of the electronic converter a virtue has thus been made of a necessity and a real improvement in practical reliability has resulted. Disturbances from other causes than lightning may result in circuit faults. Whether such faults can be counted on to clear themselves automatically depends upon the characteristics and stability of the systems that are involved. An electronic converter has a definite load limit like an inductance motor or a synchronous motor. In the grid control we have, however, excellent means for regulating the system so that those load limits are never exceeded. Such regulating systems have been incorporated in the installations now in operation as described in companion papers.

It is important that the application engineer should understand the characteristics and limitations of the several types of electronic converter.

The rectifier–inverter combination may be described as a frequency changer or a d-c power transmission depending upon whether they are located in the same station or far apart and joined by a d-c transmission line. The Mechanicville-Schenectady installation is a frequency changer as well as a transmission because the power is generated at 40 cycles and delivered at 60 cycles. Similar installations may fill a demand in the future as nonsynchronous links between 60-cycle systems which are not operated in synchronism. This type of installation is primarily adapted to exchange of power between independent systems. In its original form, it is not adapted to start a dead load. When needed, however, suitable arrangements will undoubtedly be made. An electronic d-c transformer fed from a d-c line may be used to start a dead load as shown on the accompanying oscillograms. The power thus made available may be used to start a synchronous condenser so that it can be fed from another electronic converter. This will serve to illustrate many possibilities of using the electronic power converter in one form or another. It can safely be said that with the installations of the electronic power converter already made, this new tool of the electrical industry has come out of its infancy.

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The Evolution of Standard Lines of Current Transformers for High Overcurrent Capacity

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MEMBER AIEE

Synopsis: Modern switchgear requires, more and more frequently, special current transformers capable of carrying very high fault currents. In the past, the application engineer and the design engineer were not always close together in their work on the current-transformer problem; the application engineer has often had only an approximate idea of what the design engineer could produce, while the design engineer has had only an approximate idea as to general application requirements. The design engineer has not had too sound a basis for many of his designs. His costs were high on account of the multiplicity of special designs.

This paper discusses the basis of design of current transformers for high overcurrents, and describes the co-ordination of mechanical parts with performance requirements to produce lines of current transformers in a definite and easily understood pattern of characteristics. The result is that selection of the proper current transformer is easily accomplished.

The arrangement of the line of mechanical parts and performance characteristics is such that the expense involved in manufacturing these special transformers can be considerably reduced.

IN the early days of switchgear construction, fault currents were not generally as high as they are today. Special current transformers to carry high currents were rarely needed. Today, however, special current-transformer designs for high current capacity have become common. These "special" designs have taken their place in so much switchgear that they have become in fact standard for switchgear. The basis of their design and rating becomes logically a subject of wide interest and importance.

These current transformers have been most confusing to the application engineer. He has understood that the special transformers for high overcurrent had to have, in general, either higher cost or poorer performance, but there was little generally published information to tell him how high the cost or how poor the performance. He was amazed, in some instances, when he found out. The design engineer, on the other hand, has been confused by the wide variation in performance requirements. The resulting multiplicity of special designs has cost too much to design and to manufacture.

The fundamental basis for solution of the problem is logically a design study, but the evolution of standard lines of transformers to fit all conditions is a most important part of the solution for the application engineer. An application study will be described, together with the method of setting up standard lines of current transformers.

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Design Study

The important characteristics of a switchgear current transformer may be listed (given also the insulation class and nominal current ratio)

(*a*). Fault-current capacity[1]
1. Thermal limit (one second).
2. Mechanical limit.

(*b*). Metering performance or accuracy
1. ASA metering accuracy classes.[2]
2. ASA metering burdens.[3]

(*c*). Relaying performance
1. ASA relay accuracy classes.[4]
2. ASA relay burdens.[3]

(*d*). Size and cost.

In general, it is obvious that any characteristic can be somewhat improved at the expense of one of the others. The problem is to get a best compromise of all the characteristics. Let us examine each characteristic separately.

Fault-Current Capacity

1. *Thermal limit.* This limit[1] is defined in a rather complex way which is really equivalent to defining the maximum current density (for one second) as about 90,000 amperes per square inch. To raise the thermal limit, put in more copper.

2. *Mechanical limit.* The study of the mechanical limit divides logically into two parts:

A. Calculation of forces. Various forces act to distort the coils in various ways. (See Figure 1.)

B. Calculation of strength, or the resistance to each form of distortion.

A. Calculation of Forces

The physical nature of the forces in the coils, together with the method used for their solution, is indicated in Figure 1.

Two fundamental principles are available as tools to determine the forces.

$$(a). \quad \text{Force} = F \propto Bli \tag{1}$$

$$(b). \quad \text{Force} = F \propto \frac{i^2}{2}\frac{dL}{dx} \tag{2}$$

The first principle is the more familiar, and is thus more easily used. The second principle can be stated in words, about as follows: the force on an element of a coil, in any direction (taken as x) is proportional to the rate of change of coil inductance with respect to motion of the coil element in that direction. This is a powerful method of attack, since any element or direction of motion may be chosen. The method was demonstrated by Dwight[10] and Clem[5] and used to advantage by Clem in calculating forces in transformers. Both methods are actually used, as expedient.

1. *The expanding force* (which also tends to unwind the outer coil) is most easily calculated according to the assumptions shown in Figure 2. The force

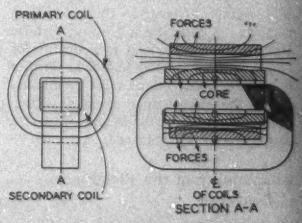

Figure 1. Physical nature of forces

Forces are indicated by the arrows in the right-hand view

In the primary coil, the forces, acting outward, with components toward the vertical centerline tend to expand the outer coil, and to crush it axially

In the secondary coil, the forces tend to crush it against the core

Further inspection of the figure indicates that if the coils are not centered about the centerline of the right-hand view, an axial force tending to slide the coils apart will develop

formula derivation, also outlined in Figure 2, is very simple. This method obviously introduces some error. However, the expanding force is not the important force if the transformers are constructed as shown in Figure 1, and actual failure is very seldom caused by it. Furthermore, even this approximate method gives more accurate results than the best available formula for axial forces, so that further refinement is without point.

2. *Unwinding force:* The principles of Figure 2 may also be used to calculate the force on the end turns of the coil which tend to unwind the coil. If the coil (Figure 4) is N turns thick, the average field strength through the end turn is $2/N$ of the average value throughout the coil itself. The ampere-turns in the outer turn is $1/N$ of the total ampere-turns in the coil. The force per inch of the end turn of a coil constructed according to Figure 4 is then $(2/N)\times(1/N)$ of the expanding force on the coil as a whole, or $2/N^2$.

3. *Axial-displacement force:* The axial forces have been calculated in a number of ways.[5,6] The method developed by Clem[5] has been found to be most accurate and easier to use. The discrepancy between the methods was found to be such that further investigation into the adequacy of Clem's method was carried out experimentally, as follows:

Experimental Determination of dM/dx

The value of dM/dx or rate of change of mutual inductance with displacement, was carefully measured by measuring M for various axial positions of the inner coil relative to the outer. The change in mutual inductance is very small indeed, but can be adequately measured by comparison with standard precision mutual inductances according to the method outlined by Fortescue.[7] This method can easily be used to measure a change in mutual inductance of 0.01 per cent. The coils used were actual current-transformer coils. Figure 3A shows the coils and gives some of the results of the measurements. The change in inductance at one centimeter displacement is only 1.4 per cent, and as the mutual inductance can be measured to not better than 0.01 per cent the measurement of dM/dx is probably not accurate to better than five per cent.

Experimental Determination of Force

The same coils were used to determine the force, according to the set up in Figure 3B. Again the displacement was accurately measurable to about 0.05 centimeter. The difference between the results of Figures 3A and 3B is about eight per cent. The discrepancy can be attributed to experimental error. The agreement is close enough to show the adequacy of the principle that $F \propto (i^2/2)(dM/dx)$.

Calculation of Force by Clem's Method[5]

The formula is (the notation is from the *original* paper)

$$F=0.88I^2a^2nN10^8\times\left[\frac{X_1}{r_1}F_1-\frac{X_2}{r_2}F_2-\frac{X_3}{r_3}F_3+\frac{X_4}{r_4}F_4\right] \quad (3)$$

F = Peak force in pounds
I = Root-mean-square amperes
n, N = Turns in the two coils, per centimeter of axial length
A, a = Effective radii of two coils

$$X_1=X-\frac{S+P}{2} \qquad X_3=X+\frac{S-P}{2}$$

$$X_2=X-\frac{S-P}{2} \qquad X_4=X+\frac{S+P}{2}$$

$$r_1=\sqrt{A^2+X_1^2} \qquad r_3=\sqrt{A^2+X_3^2}$$

$$r_2=\sqrt{A^2+X_2^2} \qquad r_4=\sqrt{A^2+X_4^2}$$

Where X = displacement

$$F_1=1+\left(\frac{a}{r_1}\right)^2\frac{3}{8}\left(\frac{A}{r_1}\right)^2+\left(\frac{a}{r_1}\right)^4\frac{5}{64}\left(\frac{A}{r_1}\right)^2\times\left[7\left(\frac{A}{r_1}\right)^2-4\right]+\left(\frac{a}{r_1}\right)^6\frac{55}{1{,}024}\left(\frac{A}{r_1}\right)^2\times\left[33\left(\frac{A}{r_1}\right)^4-36\left(\frac{A}{r_1}\right)^2+8\right], \text{ etc.} \quad (4)$$

F_2, F_3, and F_4 are similar expressions, functions of r_2, r_3, and r_4 instead of r_1.

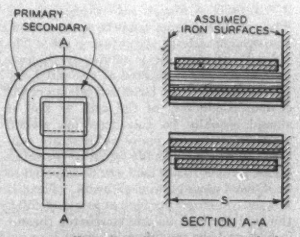

Figure 2. The expanding force can easily be calculated by $F \propto BIl$, if the flux lines are assumed to be straight lines limited at the ends of the coils by magnetic surfaces

The figure shows the lines passing straight across. $B=\dfrac{0.4\pi NI}{S}$

The force is:

$$F=\frac{11.3(NI)^2}{10^7S}$$

peak pounds per inch of coil perimeter when NI = root-mean-square symmetrical ampere turns is fully offset
S = inches length of leakage path

The numerical work in an actual problem is considerable, even with the aid of curves and tables, and it is sometimes difficult to get a true answer, because the answer is a small difference between large numbers, each one the result of considerable calculation. Much simplification is possible by the assumption that $S=P$. This is usually true in power transformers, and nearly true enough in current transformers to give satisfactory results.

Then

$$X_3=X=X_2$$

also, for small values of X,

$$r_3=r_2=A$$

and

$$F_2=F_3$$

$$\frac{X_2}{r_2}F_2=\frac{X_3}{r_3}F_3$$

$$X_1\cong-\frac{S+P}{2}\cong-X_4 \text{ and } r_1\cong r_4$$

The corresponding values of a/r and A/r will usually be so small that

$$F_1\cong F_4\cong 1.0$$

Hence

$$\frac{X_1}{r_1}F_1+\frac{X_4}{r_4}F_4=0$$

Returning to equation 3

$$\text{Force}=1.776I^2a^2Nn\frac{X}{r_2}F_2 10^{-8} \quad (5)$$

or

$$\text{Force}=1.776(N_SI_S)^2\left(\frac{a}{S}\right)^2\frac{X}{A}F_2 10^{-8} \quad (6)$$

where N_SI_S = ampere turns (root-mean-square) in coil of axial length S. F_2 is taken from the table in Clem's paper. This formula is obviously much easier to use than the original (equation 3).

Using this formula, and assuming that round coils equivalent to the actual coils in Figure 3 are those which have the same area inside the mean turn, the force comes out to be

$$\text{Force}=0.0614I^2X$$

where X is in centimeters. This compares favorably with the actual value of force by either of the other methods (Figure 3)

From measured value of $\dfrac{dM}{dx}$, $F=0.0867I^2X$ grams; 108 per cent

From measured value of force, $F=0.08I^2X$ grams; 100 per cent

From Clem's method simplified, $F=0.0614I^2X$ grams; 77 per cent

Taking the measured value as correct, the force on the actual transformer coil

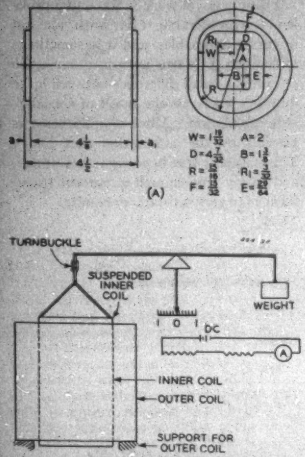

Figure 3. Coils used in experimental determination of dm/dx and F

A—The relative axial position was determined from measurements of a and a_1. The center position ($a = a_1$) did not give quite the maximum value of M. The point at which M was actually maximum was taken as center. If X is displacement from this center (centimeters), the values of M followed very closely the relation:

$$M = 0.00031731 - 0.00000425X^2$$

from which $dm/dx = 0.0000085X$ and force $= 0.0867XI^2$ (grams)

B—Procedure of measurement:

1. Adjust position and weight so that balance is attained with or without current in the coils. This will be when the coils are electrically centered.

2. Without current determine displacement (1.14 centimeters) as additional weight (1 gram) is added.

3. With current (7.8 amperes direct current) determine weight (6.55 grams) to produce same deflection.

4. Force due to current is 5.55 grams.
$F = 0.08 \times I^2X$ (compares with $0.0867\ I^2X$ from Figure 3A).

at normal current ($10\sqrt{2}$ peak amperes) and 0.1 inch (0.254 centimeter) displacement would be

$$F = 0.08 \times 2 \times 100 \times 0.254 = 4 \text{ grams}$$

At 200 times normal current the force would be $200^2 \times 4 = 160{,}000$ grams $= 352$ pounds. This compares favorably with the force of 600 pounds required to separate the coils, described later.

This method is obviously not too exact. However, it is never possible to know the possible displacement in an actual transformer with great accuracy. It is necessary to make some assumption as to maximum possible displacement, which must be assumed large enough to be on the safe side. This automatically provides a fairly large factor of safety, so that great accuracy of calculation is unnecessary. The method given will give a sufficiently accurate comparison of forces in various designs, which is all that is required for the purpose.

B. Calculation of Strength

The resistance to each force can be calculated as follows:

1. *Expanding force.* The expanding force in a coil appears as a tension in the copper which can be calculated in the same way as the tension in the walls of a cyclinder subjected to internal hydraulic pressure.

Given:

F = force per unit of circumference
d = diameter of the coil

Tension in one side $= Fd/2$ and the stress in the copper is $Fd/2$ divided by the total copper cross section. In the coils in question this tensile stress (see Figure 2) is never the critical one; failure always occurs by axial displacement.

2. *Unwinding force.* The end turn is held down in three ways:

By the Micarta terminal brace (Figure 4).
By the treated tape insulation wound tightly over the coil.
By the stiffness of the copper.

Of these, the first and third are difficult to calculate, although they are considerable. The strength of the treated tape is easily calculated, however, and is found to be sufficient to hold the end turn in place, assuming an ultimate tensile strength of 5,000 pounds per square inch for the tape. (For 0.010×1-inch tape, a breaking strength of 50 pounds.)

3. *Arching of straight side of primary coil.* The expanding force tends to arch, or bow, the straight side of the primary coil. The strength of the side is obviously at least that of a beam supported at the ends, uniformly loaded. The beam is made up of the several conductors of the coil, so that it should actually be considered as several separate beams, as many as there are conductors, which is usually equal to the number of turns N. The load can be assumed to be divided equally on each beam. Then, if F is the total force per inch of length of coil l, the load per inch on one conductor (beam) is F/N and the maximum moment is

$$\text{Moment} = \frac{Fl^2}{N8}$$

and the maximum stress is the familiar MC/I

$$\text{Stress} = \frac{\text{moment} \times {}^1/_2 \text{ conductor thickness}}{\text{moment of inertia of one conductor}}$$

$$\text{Stress} = F \times \frac{l^2}{8} \times \frac{\frac{\text{conductor thickness}}{2}}{\frac{1}{12} \text{ conductor width} \times \text{conductor thickness}^2}$$

The stress will usually come out to be about 50,000 pounds per square inch at the current at which the limiting axial force is reached. The inference is that the coil will fail by bowing out of the straight side. Actually, however, two important factors enter to reinforce the coil at this point:

1. As soon as a very slight bow has occurred, the beam is much stronger.

2. The core, backed up by a heavy steel base, takes much of the stress as soon as a slight deflection occurs.

The actual strength is very difficult to calculate. Tests to be described, however, show that this stress is not the limiting one.

4. *Resistance against axial movement.* A number of coils were made and the strength measured by actually pressing the inner coil out of the outer coil in a testing machine. The force required for the coil shown in Figure 4 was of the order of 600 pounds to start the coil moving. The cement used is a plastic, and its resistance is viscous in nature. The force required to move the coils very rapidly, as they do when actual failure occurs, is certainly higher, but it is not possible to say how much. From these tests the effective shearing strength of the cement was determined and strengths of other size coils calculated. A high-strength thermosetting cement was found to be practical for those designs made for high thermal capacity in oversize frames, to make the mechanical limit comparable with the high thermal limit. The strength of this cement is more than twice that of the plastic cement. The designs with which this cement is used have oversize copper, so that the tensile strength of the coil is increased about in proportion, and as they have, in general, more than four turns, the unwinding force was not a limit. The mechanical strengths were thus made higher in these designs in about the same ratio as the thermal limits.

Strength Tests

The critical strengths are evidently (1) the axial displacement resistance and (2) the bowing of the straight side of the coil.

The possible initial axial displacement in a coil the next size smaller than Figure 3 was deliberately made 0.16 inch by displacing the last coil layer. According to Clem's method, simplified, the axial stress was then 650 pounds at 100 times normal current, while the resisting force averaged 600 pounds. This transformer withstood 100 times normal current, as a fully offset wave could not be obtained, but at a slightly greater current the secondary coil was violently ejected, taking the core with it. Once the secondary coil moves, the force is increased, and although the current lasted only three cycles, there was ample energy delivered to do considerable damage.

Another unit was very carefully centered and cemented with high-strength cement so that an expanding force of about 8,200 pounds per inch, with a theoretical stress in the straight side, as a beam, of 98,000 pounds per square inch

at a current of 350 times normal could be developed. (Force per inch of coil length = 8,200 pounds.) This transformer actually withstood this current without damage. When the current was raised to 470 times normal fully offset, a bowing of the primary coil was produced. (Force per inch of length = 14,700 pounds.) The resulting bow did not destroy the transformer, but produced distortion of the core and frame.

The final justification of the methods consisted of calculating the mechanical limit of a number of designs, and testing

Table I

150/5 = 8 primary turns to 240 secondary turns
100/5 = 8 primary turns to 160 secondary turns
75/5 = 8 primary turns to 120 secondary turns
50/5 = 8 primary turns to 80 secondary turns
40/5 = 8 primary turns to 64 secondary turns
30/5 = 8 primary turns to 48 secondary turns

them all (over 15 units) at currents exceeding the calculated limits, without damage. Higher currents produced axial movement in some units not perfectly centered, and still higher currents destroyed a few units which were centered, by bowing of the coil.

The final strength limit is fixed by the axial force on account of the assumption that these coils cannot invariably be initially centered closer than 0.1 inch. This dissymmetry is caused by a number of variations.

1. Dissymmetry due to leads.
2. Misplacing of the last (partial) layer.
3. Dissymmetry of assembly of the coils.

It is possible to control these factors in manufacture, but as it is not practical to make any tests for symmetry of the final assembly, it is considered that it would not be conservative to assume that the initial displacement would be less than 0.1 inch.

Metering and Relay Performance

The method of calculation used has been described previously.[8] The quality of the problem to be solved can be illustrated by pointing out that the errors in transformation vary (other things being equal) approximately as follows:

Errors increase with increasing secondary burden in ohms.

Errors increase with decreasing secondary turns (about as the square).

The mechanical limit (limited by forces) increases directly with decreasing secondary turns.

The thermal limit (considered in times normal) also increases with decreasing secondary turns (again almost directly).

The interval burden, however, decreases with decreasing secondary turns (about as the square).

The relations are not exact but they illustrate the conflict between errors on the one hand and burden and current limit on the other.

Application Study

The design study is of fundamental importance, but the method by which it has been applied is of greater general interest, because it is based on ideas which are new and by which a unique result has been obtained.

Obviously a practically infinite number of current transformer designs would be required to suit all the applications exactly. Therefore, some study must be made of the field of application to allow the fundamental design principles to be applied. A limited number of standard designs is obviously desirable, but it is not clear, at first glance, what to choose as standard. The following paragraphs describe the evolution of standard lines of transformers.

Standard Overcurrent Limits: Correlation With Circuit Breakers

Standard switchgear practice[9] is to specify, for the current transformer, overcurrent capacity equal to that of the circuit breaker with which it is used. The logical conclusion, therefore, is to design a standard line of current transformers to go with each of the commonly used circuit breakers. Four standard lines of current transformers in each insulation class are indicated, designed for fault currents of 14,500, 26,000, 36,000, and 46,000 amperes.

Standard Cores

Four core sizes have been found to be sufficient to cover the range of requirements from 5- to 15-kv insulation classes. More details on the cores are given later.

Standard Primary Coils

Given the insulation class, overcurrent limit, and core size, the primary-coil design is fixed, since the primary turns and copper section are determined by the overcurrent limit. The maximum possible number of primary-coil designs is then the product of 3 (insulation classes 5, 8.7, 15 kv) times 4 (overcurrent limits listed above) times 4 (core sizes) or 48. As shown in Table III, the useful number of designs is only 28. Furthermore, as shown in the same table, 12 of these designs are taken from the standard commercial line of transformers. Finally, then, only 14 special primary coils need to be designed, built, or carried in stock.

Secondary-Coil Design

In making the core designs and the designs for the primary coils, space will have been left for a secondary coil to have substantially the same total copper cross section as that of the primary coil, so that the overcurrent density in the secondary copper will be substantially the same as n the primary, regardless of the number of secondary turns.

Table II. ASA Metering Accuracy Classes Related to Secondary Turns (for Any Core)

Secondary Turns*	Burden 0.1	Burden 0.5	Burden 2.0
240	0.3	0.3	0.3
200	0.3	0.3	0.6
160	0.3	0.3	1.2
120	0.3	0.3	2.4
100	0.3	0.6	2.4
80	0.3	0.6	4.8
60	0.6	1.2	
40	0.6	4.8	
30	1.2	4.8	

* Nominal: The actual value is slightly smaller so that the actual current ratio will come out right.

The various nominal current ratios are obtained with a given primary coil by varying the number of secondary turns. For example, the eight-turn primary coil in core number 1 is used to make the ratios shown n Table I.

As the number of turns is reduced, the copper section in each turn must be increased. Obviously all ratings will carry 150 amperes continuously. The last one, for instance, the 30/5, may accurately be described as 150/25. The design of the secondary coil is obviously very simple.

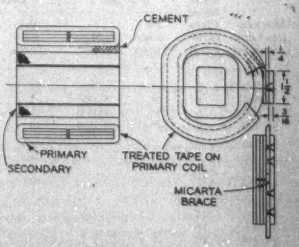

Figure 4. The primary coil shown is that of the 200-ampere rating, wound of heavy copper strip in two sections

The end (outside) turns are held down by the brace which holds the terminals together, and by the treated tape. The secondary and primary are held together by cement

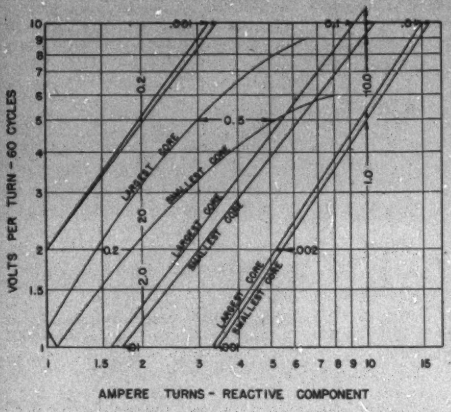

Figure 5. The saturation curves for the cores are practically identical over the lower (metering) range, so that the metering performance of all cores is the same

The curves vary widely over the upper (relaying) range, but as the relay performance rating is a function principally of the saturation voltage, it is not too difficult to work out relay performance ratings for each one

Performance

As the number of secondary turns is reduced, the performance becomes poorer. In a given core, the performance depends only on the number of secondary turns. The performance can be calculated for each number of secondary turns and core size, but the great amount of numerical work creates an impossibly tedious problem. The problem was made practical only by designing the cores as follows:

1. The saturation curves, in the lower (metering) range were made substantially identical (Figure 5).

2. The proportions of the window opening were so adjusted that the internal reactance of the secondary coil comes out the same in any core (for a given number of secondary turns).

This means that the calculation carried out for one core holds for any core, and that the performance for any design can be read from a single simple table, such as Table II.

Final Standard Lines of Transformers (Table III)

Each primary coil in Table III represents a line of transformers covering a rather small range of current ratios, as in Table I, and the performance of each of these ratios can be read from Table II. The total possible number of designs is the product of the number of primary coils times the number of secondary coils used with each primary. The number of ratios in each line is small because the highest ratio is that which has the normal maximum number of turns in the secondary, while the lowest ratio is the one which has the minimum number of secondary turns for usable performance. However, as the table shows 28 lines of transformers, which, with at least six ratios in each line, is 168 new designs, it might seem that a great deal of design work is yet to be done. However, after the 14 special primary coils have been designed, the design of the secondary coils is almost simple clerical work.

The final complete table of transformers would require considerable space and is not included. Each space in Table III is expanded, in the manner of Table I, into a line of transformers. Each line has the one *continuous* primary-current rating in all ratios. The performance characteristics fall into a consistent pattern.

The transformers are constructed in a similar way, and the fact that only four sets of mechanical parts and only 28 primary-coil designs are required reduces manufacturing expense.

The problem of selection is almost completely solved for the application engineer, since he can very quickly find the design he wants in the complete tables furnished by the manufacturer.

Control of quality is much easier. The user of the transformers can be more certain that transformers selected from a standard line of proved performance, will be more satisfactory.

Table III

Mechanical Limit (Amperes)	Insulation Class (Kilovolts)	Core No. 1 Primary Turns	Core No. 1 Thermal Limit	Core No. 2 Primary Turns	Core No. 2 Thermal Limit	Core No. 3 Primary Turns	Core No. 3 Thermal Limit	Core No. 4 Primary Turns	Core No. 4 Thermal Limit
14,500	5	8*	12,500	12	14,500	14	17,000		
26,000	5	4*	26,000	7	26,000	8	30,000		
36,000	5	3*	36,000	5	36,000	6	50,000		
46,000	5	2*	50,000	3	50,000	4	60,000		
14,500	8.7			8*	12,500	14	14,500		
26,000	8.7			4*	25,000	8	26,000		
36,000	8.7			3*	36,000	6	36,000		
46,000	8.7			2*	46,000	4	50,000		
14,500	15					8*	12,500	12	14,000
26,000	15					4*	25,000	7	27,000
36,000	15					3*	36,000	5	36,000
46,000	15					2*	46,000	4	50,000

* These primary coils are taken without change from the standard commercial lines of transformers; the transformer construction and dimensions are standard. The coils with 8, 4, 3, 2 turns, respectively are the coils for standard 150, 300, 400, and 600 amperes, respectively. The other designs are made with special primary coils. The higher-strength coil cement is used to resist the higher mechanical forces generated by the higher values of ampere turns. These designs are accordingly more expensive, but of course the performance of these designs is much better.

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Totalizing Contents of Aircraft Fuel Tanks

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THE requirement of totalizing two or more liquid levels in aircraft fuel tanks falls into two broad classifications. The first involves the addition of levels where the sequence of use is definitely established. This type is best exemplified by considering a long wing tank where the dihedral angle makes it necessary to have more than one transmitter in the tank to obtain complete coverage of the fuel contents. Figure 1 shows such an arrangement. With the fuel outlet as shown, transmitter 2 must function first. In other words, the sequence of operation is fixed so that the operation of transmitter 2 is always followed by that of transmitter 1 as fuel is withdrawn from the tank.

The second category covers the totalization of several liquid levels in different tanks where the sequence of use is not established, but where single indication of the total fuel is desired. For the three separate tanks each with its transmitter, shown in Figure 2, the sequence of use of the fuel in the three tanks may vary widely. Such variations may be caused by the puncture of one or more tanks by gunfire, by the necessity of trimming the plane, or by other abnormal changes.

Principle of Operation

In order to explain the operation of the totalizing circuit it is desirable to show first the basic principles of a similar circuit when used in the conventional manner. Figure 3 shows a typical liquid-level transmitter now used in aircraft fuel tanks. The cork float at the end of the lever floats on the surface of the fuel. As this surface level changes the motion of the float is transformed through suitable gearing and sealing mechanisms to a change in resistance of a potentiometer unit located in the head of the transmitter.

Figure 4 shows schematically this potentiometer connected to the element of the indicator on the instrument panel. This element has two coils, located 140 degrees apart, one of which is connected directly across the battery through a series resistor. The current through this coil is constant except for changes in the line voltage. The other coil is shunted by the potentiometer in the transmitter. The amount of shunting resistance, and hence the current in the indicator coil, is therefore dependent upon the position of the transmitter float and varies with the liquid level.

The vector diagram of Figure 5 further illustrates the principle of operation. The permanent-magnet rotor to which the indicator pointer is attached aligns itself with the resultant vector, a vector obtained by the addition of the constant-current-coil flux and the variable-current-coil flux. The general design of this indicator is similar to one described in an earlier paper,[1] except it has been made up in a ratio-instrument[2] form for this application.

Sequence Totalizing

In a simple two-transmitter-sequence totalizing circuit the variable-current coil of Figure 4 is double wound. Each section of this double winding is connected to a transmitter as shown schematically in Figure 6. The flux from the variable-current coil is the sum of the fluxes produced by the currents flowing in the two parts of the double-wound coil. The conditions of the system described in Figures 4 and 5 are duplicated.

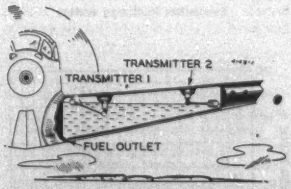

Figure 1. Installation showing necessity of two transmitters to obtain complete fuel coverage

Only one value of resultant flux is possible for any tank content; therefore, the indicator reads the correct fuel quantity. The indicator-scale distribution is established by the shape of the tank and the values of the circuit resistances.

Nonsequence Totalizing

Since the indicator must show correct readings regardless of how the fuel is distributed in the tanks being totalized, the nonsequence-totalizing system presents a different problem from the sequence-totalizing system just described.

As in the case of sequence totalizing, there is a separate winding on the variable coil in the indicator for each transmitter used. In order to make the indication of the total fuel quantity independent of the sequence of consumption, the increment of flux and ampere turns per gallon of fuel associated with each winding of the variable coil must be constant and of the same value for all tanks. The total ampere turns produced by the variable coil can then be represented by the equation:

$$NI = \Delta ni(g_1 + g_2 + g_3 + \ldots) \qquad (1)$$

where NI is the total ampere turns produced by the variable coil, Δni is the increment of ampere turns per gallon, and g_1, g_2, and g_3 are the gallons present in tanks 1, 2, and 3, respectively. In order to obtain the condition shown by this equation consideration must be given to:

1. The shape of the tanks.
2. The dimensions of the transmitters.
3. The electrical circuit.

The simplest tanks to totalize would be those having a straight line as the plot of gallons versus float angle. However, it is impractical to meet this condition

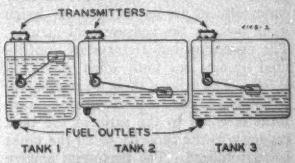

Figure 2. Installations in three different tanks with total fuel in all tanks to be indicated on a single dial

and the nearest practical approach is a tank with uniform cross section at all liquid levels. With a tank of this construction it can readily be shown that:

$$x = L(1 - \cos\theta) \qquad (2)$$

where x is the depth of the liquid, L is the length of the float lever, and θ is the angle formed by the float lever and a perpendicular to the liquid level. This equation is shown graphically in Figure 7. For uniform-cross-section tanks, the dimensions of the transmitters can be designed so that θ is kept between 60 degrees and 120 degrees to utilize the portion of the curve which is almost a straight line. Although a constant cross section is not always obtainable, it is often possible to vary the transmitter dimensions in order to utilize the curve of Figure 7 in such a manner as to compensate for the shape of the tank. Control over the characteristics of the electrical circuit can be obtained by introducing corrective resistance values R_1, R_2, R_3, and R_4 into the

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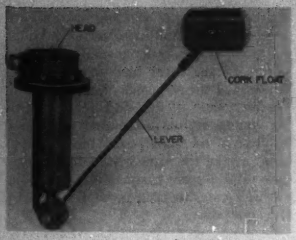

Figure 3. A typical liquid-level transmitter

proper parts of the circuit as shown in Figure 6. These resistances also provide an additional means of compensating for the nonlinear relation between gallons and float angle which may exist even when the optimum dimensions of the transmitter have been selected.

For example, consider a single section of the dual-wound coil and its accompanying transmitter potentiometer in Figure 6, where R_e represents the variable-coil-circuit resistance; R_{T1} and R_{T2} the transmitter potentiometer resistances. R_{T1} and R_{T2} always add to give R_T the total potentiometer resistance. The total ampere turns necessary to operate the indicator element are known from its design when used in the conventional manner. The maximum ampere turns are contributed by any one tank when that tank is full. The ratio of these maximum ampere turns to the total maximum ampere turns is equal to the ratio of the tank capacity to the capacity of all the tanks being totalized. The maximum ampere turns occur when g_1, g_2, and g_3 of equation 1 are equal to the capacities of tanks 1, 2, and 3, respectively.

To insure uniformity of positioning of the sections of the multiwound coil, the individual windings are all wound in a single operation keeping the several wires as closely together as possible. Each winding of the coil then has the same number of turns.

To meet the conditions of equation 1 it is necessary to vary R_1, R_T, and R_2 so that the curve of the current in the coil versus gallons in the tank is a straight line. Since in practice this straight line cannot often be attained, the closest possible compromise must be used.

To plot this current-versus-gallon curve, an intermediate curve of the tank calibration must be used. The calibration curve shows the liquid level in the tanks versus gallons. This liquid level in turn is translated into angular movement of the float lever and finally into values of per cent R_T where

$$\text{Per cent } R_T = (R_{T1}/R_T)100 \qquad (3)$$

The amount of current in the variable indicator coil for various liquid levels can then be readily calculated by solving the simple circuits of Figure 6, and the resistance values determined to give the closest approximation to a straight-line relationship between current in the variable coil and gallons in the tank. Similar curves must then be obtained for the other tanks.

When the values of R_1, R_T, and R_2 are chosen for one of the tanks the calculations for the remaining tanks become simple, providing the tanks are the same shape. When this is true the values of R_1, R_T, and R_2 are multiplied by a suitable constant proportional to the contents of the tank being considered in relation to the total contents of the system. If the other tanks are of different shapes, the values of R_1, R_T, and R_2 must be determined for each by the same process used on the first tank, so that for each tank the curve of current versus gallons is a straight line of the same slope.

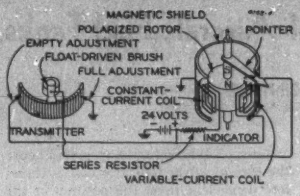

Figure 4. Schematic cut-away view of indicator and transmitter

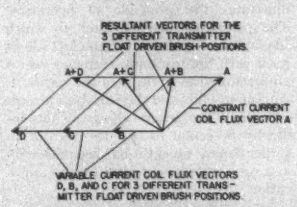
RESULTANT VECTORS FOR THE 3 DIFFERENT TRANSMITTER FLOAT DRIVEN BRUSH POSITIONS.
A+D
A+C
A+B
A
CONSTANT CURRENT COIL FLUX VECTOR A
D
C
B
VARIABLE CURRENT COIL FLUX VECTORS D, B, AND C FOR 3 DIFFERENT TRANSMITTER FLOAT DRIVEN BRUSH POSITIONS

Figure 5. Vector diagram of fluxes for three currents in the variable coil

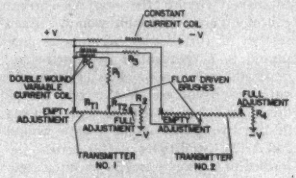

Figure 6. Schematic diagram of a two-transmitter totalizing system

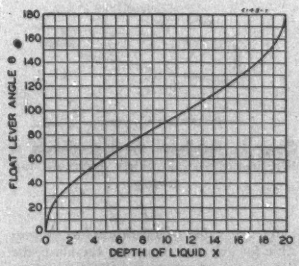

Figure 7. Curve of depth of liquid versus float-lever angle for a tank of constant cross-sectional area

$$x = L(1 - \cos\theta); \quad L = 10$$

Table I. Variations in Indication With Changes in Use Sequence

Total Fuel, Gallons	Average Indicated Gallons With Seven Various Sequences of Use						
	A	B	C	D	E	F	G
0	0	0	0	0	0	0	0
100	100	110	98	92	94	98	90
200	200	208	206	198	198	192	198
300	300	294	308	298	298	288	288
400	400	386	410	400	400	386	
500	500	500	500	500	500	500	

Sequence of use *A*—As calibrated.
Sequence of use *B*—Tanks 1, 2, and 3 simultaneously.
Sequence of use *C*—Tank 2, tank 1, tank 3.
Sequence of use *D*—Tank 1, tank 2, tank 3.
Sequence of use *E*—Tank 1, tank 3, tank 2.
Sequence of use *F*—60 per cent tank 2, 60 per cent tank 1, 100 per cent tank 3, 40 per cent tank 1, 40 per cent tank 2.
Sequence of use *G*—60 per cent tank 1, 60 per cent tank 3, 60 per cent tank 2.

Tank 1 contents—200 gallons.
Tank 2 contents—100 gallons.
Tank 3 contents—200 gallons.

Application of Nonsequence Totalizing

Figure 8 is a photograph of a totalizing-indicator element used to read the total fuel in three tanks. The variable-current coil located beneath the magnetic shield is triple wound. Manufacturing difficulties in producing this multiwound coil limit the number of windings and hence the number of tanks which can be totalized with a given-size element. Figure 9 shows the complete instrument using the element in Figure 8. The scale

Figure 8. A three-transmitter totalizing indicator element

Figure 9. A three-transmitter totalizing indicator using element of Figure 8

Ring Busses for Generating and Transmission Stations

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MEMBER AIEE

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MEMBER AIEE

IN recent years, the Commonwealth Edison Company has adopted bus layouts for generating stations and transmission terminals which differ greatly from those installed in its older stations. The purpose of this paper is to describe these developments and to discuss the application of the ring-bus principle to high-voltage installations. It appears to be an appropriate time to review the characteristics of various bus layouts in view of possible postwar expansion and rehabilitation of existing stations.

The basic problem in determining the most desirable bus layout is to obtain reliability, flexibility, and adequate relay protection, at a reasonable cost. In the earlier period of development of bus layouts in large metropolitan stations, the most important of the above factors was reliability of supply. It was found that a duplicate power supply for all transmission lines emanating from the generating station was essential for reliable service. However, as methods of station construction improved and advances were made in the development and design of station equipment and bus-protection schemes, the requirements for bus layouts in generating, distributing, and transmission stations have also changed. In addition, operating experience has indicated certain desirable features which should be incorporated in bus layouts. This paper will show how the bus arrangements used in the Commonwealth Edison system have been changing through a period of years to take advantage of improved equipment and experience in the operation of the system.

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12-Kv Busses

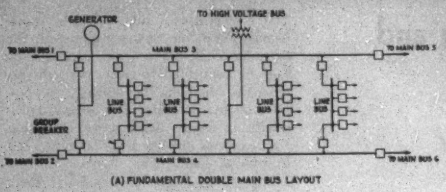
Description of Bus Layouts

The conventional type of double-bus arrangement, which was used in the Commonwealth Edison Company up to 1936, is illustrated in Figure 1A. In this arrangement, there are two sets of main busses, each set consisting of several sections separated by section tie breakers. The generators, high-voltage transformers, and line busses which feed the outgoing lines are so arranged that they may be connected to either or both sets of main busses. The substations supplied by the outgoing lines have a multiplicity of supply lines so selected that the outage of one line bus does not result in loss of load. The number of lines connected to each line bus has varied; earlier stations have three lines per line bus, while later stations have four lines per line bus.

Several variations in this conventional bus have been used. At one station the two sets of main busses are connected through two reactor ties as shown in Figure 1B. The purpose of these reactors is to reduce short-circuit currents with the two main busses operating in parallel. In this station, some of the generators, transformers, and line busses are operated closed to one of the two main busses, and the remainder to the other main bus.

In another case, reactors were used between the main bus sections as shown on Figure 1C. The advantage of this arrangement over Figure 1B is that it permits parallel operation of the two main busses with opposite bus sections solidly tied, and yet provides a reduction in short-circuit current. However, these reactors create a disadvantageous situation with respect to power flow on the outgoing lines. These lines operate in parallel at the substation end, with the result that any phase-angle displacement at the generating busses results in undesirable circulating currents.

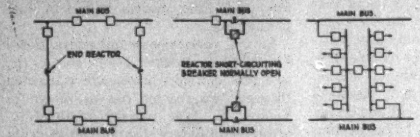
At one station the simplification shown on Figure 1D was used. In this



(A) FUNDAMENTAL DOUBLE MAIN BUS LAYOUT

Figure 1. Double-main-bus layouts for generating and distributing stations

Only operating disconnecting switches shown in diagrams



(B) DOUBLE MAIN BUS WITH END REACTORS

(C) DOUBLE MAIN BUS WITH REACTOR TIES BETWEEN BUS SECTIONS

(D) METHOD OF REDUCING NUMBER OF GROUP BREAKERS BY 25 %

layout, the line busses are directly connected to only one main bus and each pair of adjacent line busses are tied through a group breaker. This scheme reduces the number of group breakers required for a pair of line busses by 25 per cent. Because of the method of operation used, the loss of flexibility entailed by the use of this scheme is of negligible importance. However, this arrangement required a larger group breaker, inasmuch as a group breaker may be required to supply two line busses.

In the early 1930's, a new distributing station was planned to receive power from the 66,000-volt transmission system for distribution at 12,000 volts. This station was to be built for an ultimate of 80 12,000-volt lines. At the time, operating experience with the conventional double-bus arrangement of Figure 1 was reviewed, and it was found that the number of bus outages was so low that the duplication of busses was not justified. This study resulted in the adoption of the bus layout shown in Figure 2. Two rings are used in this layout because of the sectionalized operating of the 12-kv system. This method of operation is described in another part of the paper.

This new type of bus layout is fundamentally a ring bus in which the distribution lines are connected directly to the main ring. In this way, the main busses used in the conventional double bus are eliminated. The use of this plan results in the elimination of a great deal of bus equipment and approximately 40 per cent of the number of breakers required other than line breakers. In this station five outgoing lines are connected to each bus section, compared to a maximum of four lines per line bus in the older stations. One disadvantage of this bus arrangement is that the supply transformers are connected to the same bus

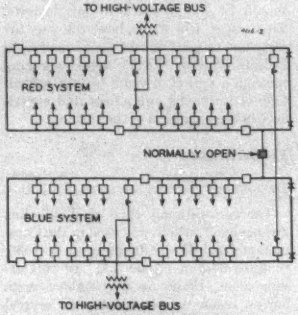


Figure 2. 12-kv ring-bus layout with one breaker between bus sections

Bus sections may be added by cutting ring at points indicated and extending the main rings

as the lines, whereas in the double bus the transformers are connected to the main busses while the lines are connected to the line busses. The ring bus has an advantage over the straight bus with respect to the concentration of current in the bus. With the ring bus, there is a more equal distribution of the current due to the fact that the supply current can flow in two directions to the load.

The operating experience with the layout of Figure 2 proved to be satisfactory except for one situation which is inherent in all bus schemes which have only one tie breaker between bus sections. With this type of bus separation, trouble in a bus section breaker can cause an outage of two bus sections, thus interrupting a sizable proportion of the entire station. Although such an occurrence is extremely rare, it would be advantageous from a system point of view, if any one case of trouble would cause the outage of only one bus section. This improvement was obtained in a later development shown in Figure 3 by using two breakers in series between bus sections. The only essential difference between Figures 2 and 3 is in the connection between bus sections.

Operation of 12-Kv Busses

The design of a fundamental bus layout is closely related to the method of operating the system. In the Chicago system, the principle of sectionalization has been one of the corner stones of reliable power supply. With this type of operation any one case of trouble is confined to approximately one-half of the system. All generating stations and transmission terminals are divided into two parts, known as the red and blue systems. At some stations, the two systems are normally operated completely separated from each other. At other stations, the red and blue systems are normally operated in parallel, but automatic sectionalization takes place whenever a heavy fault occurs on either system. This automatic sectionalization, which is accomplished by relay action, separates the station into two parts without causing the outage of any lines or equipment. The method of operating a particular station depends on the magnitude of short-circuit currents and the balance between the load and capacity. It would be desirable to operate sectionalized at all stations, but in some locations it is not economical to provide sufficient equipment to make possible this method of operation.

The ring bus is well adapted to the type of sectionalized operation used in Chicago. In the bus layouts shown in Figures 2 and 3, two rings are used, one ring constituting the red system and the other the blue system. An important advantage of the ring bus is that it can operate sectionalized even though a bus outage occurs. In the double-bus layout, Figure 1A, a main bus outage causes the loss of a considerable amount of equipment, with the result that when such an outage occurs the red and blue systems must be operated solidly tied, and without automatic sectionalization.

Various methods are provided for the normal operation of the two rings. In the diagram of Figure 2, the two rings can be paralleled directly, through reactors, or operated completely separated. In the diagram of Figure 3, the rings may be tied through reactors, or tied solidly through connections to an adjacent station. There is also a tie between the rings through the two windings of the supply transformer; however, this tie is of relatively high reactance and represents a weak link between the systems. The two-winding generator shown constitutes a relatively heavy tie between the systems. Automatic sectionalization is provided to disconnect this generator from the system in trouble. The

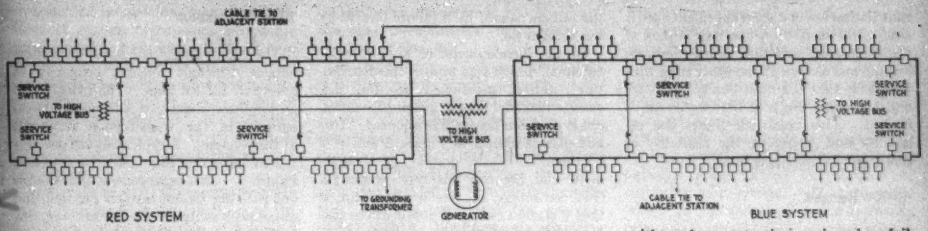


Figure 3. 12-kv ring-bus layout with two breakers in series between bus sections

method of operation actually used at these stations will depend on the magnitude of fault currents and on the balance between load and capacity as previously mentioned.

Bus Protection

Although relay protection of station busses greatly improves reliability, in the earlier Chicago stations no bus protection was used. The current transformers then available were considered to be too hazardous from an insulation viewpoint to be installed in station busses. Also, the electrical performance of these transformers and the types of relays available were not sufficiently good to make possible a reliable relaying system. On the other hand, because of the methods of construction used bus faults were considered to be too infrequent to justify the added risk incurred by the use of the protective equipment then available. This combination of circumstances resulted in all the earlier stations in Chicago being installed without bus protection.

In the early 1920's, the isolated-phase method of construction was developed and used for all station projects. This method of station construction makes possible a very simple and reliable type of bus protection known as the fault bus.[1] The operating record of this type of bus protection has been very satisfactory, inasmuch as all primary faults have been cleared correctly and quickly. In the past ten years, there have been 12 primary failures on the 66-kv and 12-kv busses at generating stations due to insulator and bushing failures and system operating errors, and these have all been cleared by the fault bus with a minimum of damage and disturbance to the system. In addition to these correct operations, there have been five unnecessary operations caused by low-voltage d-c and a-c circuits coming in contact with the fault bus. Some of the operations have been due to the failure of low-voltage circuits, and others to the improper use of the fault bus by personnel. An example of the latter case is the use of fault bus for grounding welders. These incorrect operations can be reduced to a minimum by using induction relays to prevent operation due to direct current, and by taking precaution to eliminate incorrect use of the fault bus by personnel.

An interesting point in connection with fault-bus protection is its application to the ring bus shown on Figure 2. If a fault occurs on a bus section breaker, the fault bus will instantly disconnect one of the busses to which the section breaker is connected. If this operation does not clear the fault, the other bus section connected to the breaker is cleared. In this manner, a fault on a section breaker may or may not interrupt two bus sections. The possibility of tripping two bus sections for one case of trouble can be eliminated by using two bus section breakers in series as shown in Figure 3. As discussed previously, this undesirable situation also exists in the double-bus layout.

While earlier stations were installed without bus protection, serious bus failures experienced by other companies, together with the development of improved current transformers and relays, have led to the addition of bus protection to these earlier busses. Conventional methods of bus differential relaying using induction overcurrent relays have been used. In one special case, impedance relays have been installed for bus protection. Up to the present time there have been no automatic operations of the bus differential or impedance relay schemes.

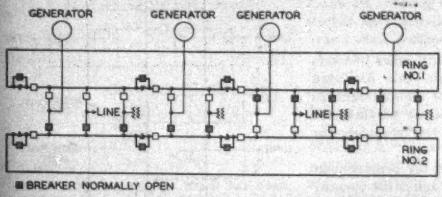


Figure 4 (left). 22-kv ring-bus layout with provisions for connecting any unit to either ring

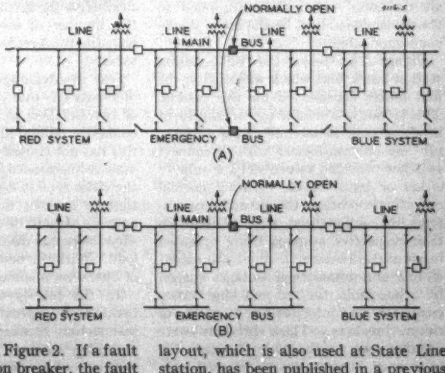


Figure 5 (right). Bus layouts used in the early development of the 66-kv system

A—Main-bus sections tied through one breaker

B—Main-bus sections tied through two breakers in series

22-Kv Busses

The first type of ring bus used in the Chicago area is shown in Figure 4. This bus was installed in a bulk power generating station operating at 22 kv. A detailed discussion of this type of ring-bus layout, which is also used at State Line station, has been published in a previous paper.[2]

This bus is a double ring in which each generator winding and transformer has connections to both rings. The bus sections of each ring are separated by a breaker and reactor in series with provisions to short-circuit the reactor by a second breaker. Experience has indicated that sufficient operating flexibility and reliability can be obtained with fewer breakers than the number shown in Figure 4.

The 22-kv. ring busses are oil-filled metal-clad structures which are protected by a fault-bus system. An impor-

tant limitation of the arrangement used is that a bus section on one ring is part of the same steel structure as the similarly located bus section on the other ring, with the result that the fault-bus system cannot determine which of the two busses is faulted. This condition limits the reliability and, therefore, the flexibility of this type of double-ring bus.

66-Kv Busses

The transmission system within Chicago is a 66-kv underground system which in effect is a cable bus running the full length of the city, interconnecting

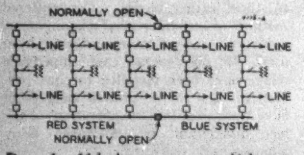


Figure 6. 66-kv bus arrangement which combines the principles of the double-main-bus and ring-bus layouts

sources of supply with load distribution centers.[1] This cable bus is operated in two sections known as the red and blue systems which correspond to the 12-kv red and blue systems. The principle of isolated phase construction is used at all the 66-kv terminals and applied to the transmission lines by the use of single-conductor cable.

Figure 5A shows the fundamental station bus layout which was used in the first busses constructed for this system. This layout is a double-bus arrangement in which there is only one circuit breaker per line or transformer with disconnect switches provided to connect the unit to either or both busses. During normal operating conditions the red and blue systems are sectionalized, with all units on their respective systems being operated in parallel. In order to limit the extent of line and transformer outages caused by a bus fault, the red and blue busses were each split into sections by means of circuit breakers. These breakers were installed only on the main bus since the emergency busses were to be used only when a main bus section was out of service.

An important limitation in the operation of this type of bus layout is that disconnect switches must be operated under load when it is desired to transfer units from one bus to another. Another disadvantage inherent in this type of layout is that a case of trouble on a bus section breaker interrupts a very large amount of capacity. As a result, the bus layout was rearranged to provide two breakers in series between bus sections, as shown in Figure 5B. This principle is the same as is used to limit the outage caused by a failure of a 12-kv bus section tie.

In the development of a new 66-kv terminal, which was part of the distributing station mentioned in the discussion of 12-kv busses, a radically different type of bus layout was adopted. This bus plan is shown in Figure 6 and is a combination of the double-bus arrangement and the ring-bus type of design. One advantage of this arrangement is that a station fault will result in the loss of a minimum number of units. For example, a bus fault necessitates the maximum loss of only one unit; whereas the layout of Figure 5 will cause a loss of two or more units. Another advantage is the increased flexibility of operation; there are many more possible arrangements of the system with a layout of Figure 6 as compared with Figure 5. Although

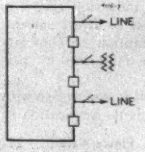


Figure 7. An initial installation of the bus arrangement shown in Figure 6

additional line and transformer breakers are required to obtain this increased flexibility, the layout of Figure 6 reduces the number of section tie breakers, so that the total remains approximately the same.

One disadvantage of the arrangement of Figure 6 is that it requires the opening of two breakers at each terminal to disconnect a faulted line or transformer, but this has not caused any trouble. As previously mentioned, one disadvantage of the older type of bus layout was the fact that to transfer units from one bus to another without de-energizing, it is necessary to operate disconnect switches under load. With the new bus layout, this type of operation is unnecessary.

In the bus layout of Figure 6, all breakers are operated closed except the bus section breakers separating the red and blue systems. The fault-bus system is used to protect the main busses, but the sections of bus to which the lines and transformers are connected are protected by the line and transformer relays. This illustrates one of the basic principles of the ring bus; from the standpoint of protection there is no bus because each section of the bus can be treated as a part of the unit to which it is connected.

In a later development, the bus plan of Figure 6 was adopted as the ultimate diagram. However, in the initial step there are only two lines and one transformer and the layout consists of the ring bus shown in Figure 7.

132-Kv Busses

The high-voltage transmission system outside Chicago consists primarily of overhead 132-kv lines. The principle of group-phase construction is used almost entirely in the transmission terminals of this system. A typical layout used for 132-kv busses on this system is shown in Figure 8. This arrangement is a double bus with one circuit breaker per unit and disconnect switches to connect the line to either of the two busses. A bus tie breaker is provided with necessary connections so that it can be used either as a bus tie or as a unit breaker. This type of bus layout was designed primarily for parallel operation of the 132-kv lines.

At the present time, the 132-kv system is operated sectionalized for the purpose of limiting the effect of faults on the stability of the system. With this method of operation, the type of bus shown in Figure 8 lacks operating flexibility. In order to take a breaker out of service either the bus tie breaker must be used for line protection, or the line must oper-

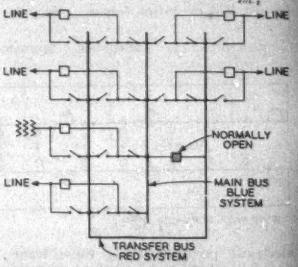


Figure 8. Double-main-bus layout used for 132-kv terminals

ate without a breaker. In the first case, sectionalization cannot be maintained, while in the second case no relay protection is provided for the line.

Practically all the busses on the 132-kv system were installed without bus protection. Operating experience has indicated the desirability of providing bus protection at these terminals, inasmuch as there has been an average of about one bus fault per year on nine 132-kv terminals of this system. These faults have been due to operating errors in grounding live busses, insulator and bushing flashover, and conductors coming in contact with each other due to insulator breakage. Investigations have been made to determine the feasibility of applying bus protection to these terminals. It was found that fault-bus protection could not be used because of the design of the steel structures. This study also indicated that the application of differential protection to these busses would be very

complicated because the many combinations of system connections which are possible make it extremely difficult and costly to install a reliable and high-speed bus differential scheme that will satisfy all operating conditions. As a result of the difficulties involved in providing bus protection, most of these terminals are still operating without this type of protection.

Studies have been in progress recently which indicate that the principles of the ring bus could be advantageously applied to 132-kv terminals. One arrangement which has been studied is the single ring bus shown in Figure 9, which requires only one breaker for each line or transformer. The principal difference between this layout and that of Figure 6 is that the latter uses a larger number of breakers which results in a higher degree of flexibility. In both types of layout, the bus sections are relayed as part of the line or transformer connected to that bus section.

The most important advantage of the ring bus over the arrangement of Figure

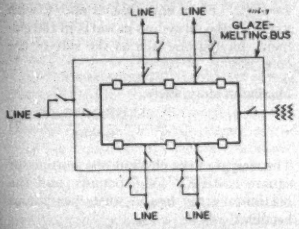


Figure 9. Single ring bus which has been studied for application to high-voltage terminals where all units are normally paralleled

8 is that bus protection is automatically provided. Also, a bus fault will affect system stability to a lesser degree if the ring bus is used, because as mentioned previously, the ring bus reduces to a minimum the number of units which must be disconnected for a bus fault. Another advantage of the ring bus is that any breaker in the ring can be taken out of service for maintenance work without disrupting the operation of the remainder of the system. However, if a fault should occur on a line or transformer while this maintenance work is being done, there is a possibility of losing other units in addition to the faulted unit. This characteristic of the ring bus is generally not of great importance during periods of light load when maintenance work is performed, but it does make the single ring unsuitable for use at terminals which are operated with the busses sectionalized. When a line or transformer is to be out of service for a long period, the disconnects on this particular unit can be opened and the ring re-established by closing the breakers of this unit.

An important problem arises in connection with operating arrangements for the melting of glaze on transmission lines. In the Chicago area, glaze melting is accomplished by isolating generators and transmission lines, and operating them with the transmission lines grounded and with reduced voltage on the generators. With conventional bus arrangements such as Figure 8, glaze-melting procedures may be effected by using one bus for load-carrying purposes and the other bus for glaze-melting purposes. Obviously this could not be done with the ring bus, but the problem can be solved by providing a separate glaze-melting bus with disconnect switches at

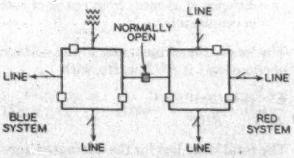


Figure 10. Double ring bus which has been studied for application to high-voltage terminals where sectionalized operation is used

each terminal for connecting lines to this bus as shown in Figure 9.

In the conventional type of bus, one set of potential transformers can be used to provide potential for metering and relaying. In order to provide for all possible operating conditions with the ring bus, it would be necessary to use more than one set of potential transformers.

Other arrangements of the ring bus have been studied. Figure 10 shows a double ring bus which requires one additional circuit breaker in order to accommodate the same number of lines and transformers as in a single ring. An advantage of the double ring bus is that a fault on one line does not break the ring. Also, this arrangement is desirable for those cases where the bus is to be operated in two systems, one ring being used for each system, without requiring any more breakers than are used on the double bus arrangement of Figure 8. However, the double ring does not have the same degree of flexibility as the bus layouts of Figures 6 and 8 for transferring units from one system to the other.

The ring bus shown in Figure 11 has desirable features for application at bulk-power generating stations. In addition to the advantages offered by the single ring bus previously mentioned, this layout reduces considerably the number of circuit breakers required without much sacrifice in the reliability of the lines, since transformer faults are very rare compared with line faults. For the case shown, only six breakers are required, while the layout of Figure 9 would require ten breakers.

The most desirable type of bus layout for any specific high-voltage installation depends primarily on the method of operating the system. At a terminal where all the units are to be normally operated in parallel the single ring (Figure 9) is the most suitable. If the terminal

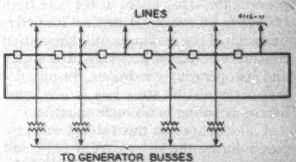


Figure 11. Single ring high-voltage bus which has been studied for application to bulk-power-supply generating stations

is to be operated sectionalized in two parts with only a limited need for transferring units from one system to the other, the double ring (Figure 10) is the logical choice. On the other hand, if maximum operating flexibility is required the principle shown in the bus layout of Figure 6 should be adopted.

This section of the paper has discussed the advantages of applying the ring bus construction to new 132 kv structures. No attempt has been made in this paper to show the cost of rebuilding existing installations to incorporate the ring-bus design, or whether the cost of such rebuilding would be justified.

Conclusion

This paper has described the development of high-voltage bus layouts in the Commonwealth Edison Company. It has attempted to show that the characteristics of the ring bus provide various advantages from the standpoint of flexibility of operation, ease of providing protection, simplicity of maintenance, and economy in investment.

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Interlamination Resistance

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IN laminated-core structures for transformers and rotating machines the need for adequate interlamination resistance becomes more necessary as the core structure increases in size. Where considerable pressures are exerted on the core laminations, a safe value of interlamination resistance must be maintained to prevent the stray losses in the core from becoming excessive. A method for determination of the minimum interlamination resistance required in terms of the core and its operating conditions, for any degree of permissible stray loss, is developed herein, resulting in a simple equation.

A short paper on this subject was prepared during the latter part of 1943, and encouraging comments on it led to the writing of this paper. It is recognized that this problem undoubtedly has been investigated or considered frequently, privately or otherwise, since the advent of the laminated core. In recent years, however, it has been the author's conviction that a more complete understanding should be had of the major factors influencing stray losses in the core. Although the consideration of the problem is not so rigorous as it could be, it is believed that, for designers of core structures, the resulting equations provide adequate protection in determining the minimum interlamination resistance required.

Figure 1 shows a section of a rectangular core of width W and height of lamination stack aW. The flux density and interlamination resistance are assumed to be uniform throughout the core structure, and the electrical resistance of the silicon steel of the laminations is negligible when compared with interlamination resistance. For analysis the core is divided by a neutral plane into two equal parts, each $W/2$ wide.

The voltage causing the stray-loss currents to flow is perpendicular to the laminations, and its value is a function of the lamination width. Consider an element dx in width, one centimeter in height, and aW long, having a resistance R, with the voltage causing the stray loss to be applied over the element length aW. The position of the element is x distant from the neutral plane of the core, and the core area enclosed becomes xaW. The resulting voltage due to the flux through this area will be that for one turn and will be concentrated across the element length aW. This can be stated as:

$$\frac{E}{N}=\frac{4.44fBaWKx}{10^8}\text{ volts per turn} \tag{1}$$

where

f = frequency in cycles per second
B = flux density in kilogausses
a = ratio of height of stack to lamination width
W = lamination width in centimeters
K = space factor
x = distance of element from center of core in centimeters

The loss in the element due to the voltage of equation 1 is E^2/R watts, with

$$\frac{E^2}{R}=\frac{(4.44fBaWKx)^2}{R10^{16}}\text{ watts} \tag{2}$$

The total stray loss for the laminated-core width $x=0$ to $x=W/2$ is:

$$\text{Total watts}=\frac{(4.44fBaWK)^2}{R10^{16}}\int_0^{W/2}x^2dx$$

$$=\frac{(4.44faKB)^2W^3}{24R10^{16}} \tag{3}$$

Let the resistance

$$R=\frac{raW}{t}\text{ ohms} \tag{4}$$

for the element having a cross section of one centimeter square and aW long, with r being the interlamination resistance in ohms per square centimeter per lamination and t the lamination thickness in centimeters. The weight of the core for the total stray loss of equation 3 is $0.5aW^2dK/453.6$ pounds, where d is the density of the core material in grams per cubic centimeter. Substitution for R in equation 3 and division by the weight of the core involved gives the average stray loss in watts per pound:

$$\frac{\text{Watts}}{\text{Pound}}=\frac{1.2211f^2B^2W_s^2Kt_s}{rd10^8} \tag{5}$$

with W_s and t_s being expressed now in inches. With P in watts per pound for the core material at flux density B and frequency f, the ratio of the stray loss to core loss, stated as a percentage, %, becomes:

$$\%=\frac{1.2211f^2B^2W_s^2Kt_s}{rdP10^4} \tag{6}$$

and if we solve for the interlamination resistance r,

$$r=\frac{1.2211f^2B^2W_s^2Kt_s}{\%dP10^4}\text{ ohms per square centimeter per lamination} \tag{6a}$$

It should be observed that the interlamination resistance r varies as the square of the frequency, the flux density, and the lamination width.

Further analysis shows, however, that the maximum stray-loss voltage occurs at the lamination edge of the core when $x=W/2$. From equations 2 and 4, with $x=W/2$, the stray loss in watts in the element, having one side as the side of the core, is:

$$\text{Maximum stray watts}=\frac{(4.44fBKW)^2taW}{4r10^{16}} \tag{7}$$

The weight of the element one centimeter square is $aWKd/453.6$ pounds, and the maximum stray loss in watts per pound becomes:

$$\frac{\text{Watts}}{\text{Pound}}=\frac{3.6633f^2B^2W_s^2Kt_s}{rd10^8} \tag{8}$$

with W_s and t_s expressed in inches.

With P in watts per pound for the core loss at B and f, the ratio of the maximum stray loss to core loss, stated as a percentage, %, is

$$\%=\frac{3.6633f^2B^2W_s^2Kt_s}{rdP10^4} \tag{9}$$

and, if we solve for the interlamination resistance r,

$$r=\frac{3.6633f^2B^2W_s^2Kt_s}{\%dP10^4}\text{ ohms per square centimeter per lamination} \tag{9a}$$

If equations 9a and 6a are compared, it will be observed that, with all factors the same, including the percentage, the interlamination resistance as calculated from equation 9a is three times the value obtained from equation 6a. But as the voltage causing the stray loss is maximum at the lamination edge of the core, the interlamination resistance should be calculated for this condition (equation 9a) rather than for the average stray loss (equation 6a). Furthermore, the maxi-

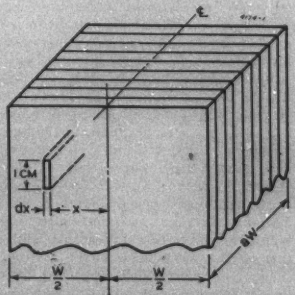

Figure 1. Section of laminated core

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mum voltage occurs where the lamination-edge condition is an important factor, that is, degree of burring and edge distortion which must be controlled to prevent low interlamination resistance.

If, for instance, in using equation 9a it is assumed that the per cent maximum stray loss to core loss at the lamination edge is nine per cent and the value of r is determined, then the per cent average stray loss to core loss becomes one third or three per cent. This is another way of showing the desirability of using equation 9a rather than equation 6a.

The interlamination resistance r is the average value in ohms per square centimeter of lamination and is the sum of all factors affecting its value. Not only does it include the resistance of the core-plating and surface oxides, but it also reflects the condition of the lamination surface and edges, stray metallic particles on the surface that may short-circuit adjacent laminations, and so forth. Furthermore and of major importance, it is the resistance that must be in effect at the pressure applied to the core and the temperature at which the core operates to assure the percentage of stray loss to be within the value chosen.

In applying equation 9a, the relation of B^2 to P should be examined. An examination of several commercial grades of silicon steel, as used for the laminations in rotating machines and transformers, in the flux density range of 8 to 15 kilogausses, shows that the ratio of B^2 to P can be considered a constant within an error of about plus or minus five per cent. This ratio states that the core loss varies as the square of the flux density, and for practical purposes the error involved is negligible in this application. This ratio also can be considered as a figure of merit for the steel used, as the greater its value the lower the core loss, for a given thickness.

If $B^2/P=C$ (a constant) is considered for the grade and thickness of the core steel used, the number of design curves that need be prepared for ready reference is simplified and reduced. Such curves can be drawn with the lamination width (W) as the independent variable, the interlamination resistance (r) as the dependent variable, with various values of the ratio of stray loss to core loss in per cent (%) as the parameter. The thickness (t), frequency (f), density (d), and space factor (K) are usually the same for many designs, with the first two, (t) and (f), usually not having more than two or three standard values.

Figure 2 illustrates such a design curve, using a 29 gauge (0.014 inch) commercial grade of transformer 52 silicon-steel sheet, with the core-loss-test specimen cut parallel to the grain of rolling and annealed. This test condition simulates the laminations in a transformer, and for this grade of steel $C=B^2/P=222$, being the average value in the flux-density range of 8 to 15 kilogausses. With $t=0.014$ inch, $f=60$

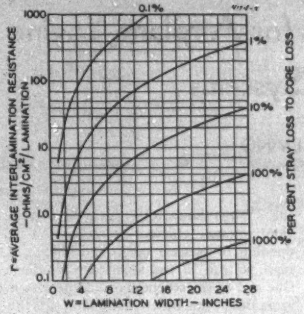

Figure 2. Variation of interlamination resistance with lamination width and per cent stray loss to core loss

For the conditions:

$$r=\frac{3.6633\,f^2B^2W_a^3Kt_a}{\%dP10^4}=\frac{0.50279\,W_a^3}{\%}$$

ohms per square centimeter per lamination

where

$f=60$ cycles
$K=0.92$
$d=7.5$
$B^2/P=222$
$t_a=0.014$ inch

cycles, $d=7.5$, $K=0.92$ and % having values of 0.1, 1.0, 10, 100, and 1,000, the curves of Figure 2 were obtained. Such curves clearly show the values of interlamination resistance necessary to control the stray loss, as well as those values that will allow excessive stray loss with the danger of hot spots developing, further reducing the interlamination resistance progressively to the point where the core laminations may melt, causing eventual failure of the apparatus. Experience in applying these curves to such conditions just mentioned has substantiated the soundness of the analysis.

In the case of large transformers where the cores usually are bolted along the middle of the lamination, the pressure is maximum where the stray-loss voltage is minimum, with the pressure at the lamination edges being lower than at the center. By calculating from equation 9a the resistance for the maximum voltage, this value becomes the minimum interlamination resistance for the maximum pressure and operating temperature for the core, thus constituting the limiting and safe conditions. Whatever additional safety factor is desired can be multiplied by this calculated interlamination resistance. The same considerations also apply to the cores of rotating machines.

If the laminations on one side of the core are short-circuited together, the stray loss in the core increases four times as the voltage is doubled on the nonshort-circuited side. Furthermore, if the interlamination resistance is broken down, because of the increased voltage, the stray losses will increase more than four times.

In large symmetrical transformer cores bolted down the center of the laminations short-circuiting of the core by the bolts has no adverse effect, so long as the interlamination resistance is uniform throughout the core. For practical purposes, however, it is desirable to insulate all bolts in case of nonuniformity in the core structure, even though the ratio of total stray loss to core loss of the assembled core is within the allowed value.

The measurement of the interlamination resistance of the finished laminations becomes most desirable as a means of quality control in the manufacturer's plant toward assuring a resistance greater than the calculated minimum. The measurement of this resistance should be made on the specimens subjected to the maximum pressure, the maximum temperature and the maximum voltage to be encountered in the core. The rms voltage is given by equation 10,

$$E=\frac{1.4319fBaW_a^3K}{10^4}\text{ volts}\qquad(10)$$

where W_a is in inches.

A standard test method in general use is that for measuring interlamination resistance, as given in the American Society for Testing Materials *Standard Method A-34*. The test specimen is composed of 3x25-centimeter strips that can be processed in the same manner as are the laminations. It is essential that, whatever specimen is used to measure the resistance, it should be prepared in the same manner as are the laminations, so that not only the surface of the specimen but also the edge effects are included in the measurement.

The pressure can be applied readily, and the heating of the specimen can be accomplished by various methods. The testing at temperature is important, especially where core temperatures are higher than those heretofore considered normal, such as encountered in air-cooled inorganically insulated coils and cores. While the organic core-plate varnishes, when properly applied and baked on the lamination, will withstand pressure and voltage at higher core temperatures, the same core plate improperly processed or cured may flow and not give the desired insulation to withstand the voltage and pressure. Inorganic core plates are available, which will withstand lamination annealing temperatures and yield suitable values of interlamination resistance for large cores.

In conclusion it may be said that an equation has been developed wherein the minimum interlamination resistance can be calculated for the maximum stray-loss voltage to be encountered in a uniform core structure for a given percentage of maximum stray loss to core loss. This value of resistance is that to be in effect at the temperature and pressures at which the core structure is to operate. The importance of quality control of interlamination resistance, especially in large

Battery Booster Coils for Airplane-Engine Ignition Systems

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THE use of battery booster coils and problems in connection therewith requires an understanding of engine ignition-system design and operation. Figure 1 illustrates a complete ignition system consisting of ignition switch, two magnetos, radio-shielded harness, spark plugs and booster magneto. One magneto is illustrated completely assembled, and the other in skeleton form showing electric and magnetic circuits.

The magneto primary winding is grounded at one end and connected to the insulated breaker contact at the other end. A capacitor, as in all vibrator systems, is connected across the breaker contacts. The insulated breaker contact and ungrounded side of the primary winding are connected to a terminal on the magneto housing. This terminal is connected to ground through the ignition switch. When the switch is in the "off" position, a direct path to ground is provided the primary current. Therefore, when the breaker contacts open, the primary current is not interrupted, preventing induction of high voltage in the secondary winding. When the switch is in the "on" position, primary current is interrupted by opening of breaker contacts inducing a high voltage in the secondary winding. One end of the secondary winding also is grounded; the other terminates at the high-voltage insert on the coil. Current in the high-voltage circuit is conducted to the central insert of the distributor fingers by means of a carbon brush, from there to the high-voltage segment of the distributor finger, and across a small air gap to the contacts of the distributor block. High-voltage cables in the distributor block then carry it to the spark plugs where the discharges occur.

The distributor finger is secured to the large distributor gear which is driven by a smaller gear located on the drive shaft of the rotating magnet. The ratio between these two gears is always such that the distributor finger is driven at one-half engine crankshaft speed. This ratio insures proper distribution of the high-voltage current to the spark plugs in accordance with the firing order of the particular engine.

Practically all aircraft engines operate on the four-stroke-cycle principle. Consequently the number of sparks required for each complete revolution of the crankshaft is equal to one-half the number of cylinders. The number of sparks produced by each revolution of the rotating magnet is equal to the number of its poles. Therefore, the ratio of speed at which the rotating magnet is driven to that of the engine crankshaft is always half the number of cylinders on the engine divided by the number of poles on the rotating magnet.

Numbers on the distributor block denote magneto sparking order and do not represent the firing order of the engine. Distributor-block position marked 1 must be connected to cylinder 1, distributor-block position 2 to the second cylinder to fire, and so on.

Sparks are not produced until the rotating magnet is turned at or above a specified number of revolutions per minute, at which speed the rate of change of flux linkages is sufficiently high to produce the required primary current and resultant high-voltage output. The speed varies for different types of magnetos, the average is 100 rpm, and the minimum is approximately 60 rpm. This is known as the "coming-in speed" of the magneto.

Starting of airplane engines has always provided a problem from the ignition engineer's point of view, and many ideas have been introduced in an attempt to provide ideal ignition conditions without increasing the weight of the system. A source of external high-voltage current is provided for starting purposes when conditions make it impossible to rotate the engine crankshaft fast enough to produce coming-in speed of the magneto. This may be in the form of a booster magneto, high-voltage booster coil or low-voltage starting vibrator.

The high-voltage booster coil of the vibratory type has superseded the motor or manually operated booster magneto. This is a device for obtaining a high intermittent voltage from a source of steady low voltage, such as a battery, accomplished by electromagnetic induction (see Figure 2). A primary winding of relatively few turns and a secondary winding of many turns are wound on a common

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transformers and rotating machines, is reviewed, and test methods are indicated.

Appendix

Since the preparation of this paper, the author's attention was called to the paper by L. V. Bewley and Hillel Poritsky,[1] wherein a rigorous analysis is applied to stray losses in the core. Their equation 38, giving the stray loss in watts per centimeter of transformer core, was found to be the same as equation 5 given in this paper. As the transformation may be of interest, it is as follows:

$$W = \frac{\lambda y}{24}\left(\frac{\omega\phi_s}{10^8}\right)^2 \frac{a}{b} \text{ watts per centimeter of core length} \quad (38)$$

where

λy = conductivity across the laminations
$\omega = 2\pi f$, with f in cycles per second
ϕ_s = total flux, peak value
a = lamination width
b = height of lamination stack

The factor a corresponds to W and b to aW, with $\phi_s = BKaW^2$. The weight of the core one centimeter is $aW^2Kd/453.6$ pounds. Substitution in equation 38 gives:

$$\frac{\text{Watts}}{\text{Pound}} = \frac{\lambda y 4\pi^2 f^2 B^2 W^2 K 453.6}{24 d 10^{16}} \quad (38a)$$

The conductivity λy is equal to t/r, and equation 38a becomes:

$$\frac{\text{Watts}}{\text{Pound}} = \frac{4\pi^2 f^2 B^2 W^2 K t 453.6}{24 d r 10^{16}} \quad (38b)$$

and with W and t in inches, equation 38b becomes

$$\frac{\text{Watts}}{\text{Pound}} = \frac{1.2224 f^2 B^2 W_s^2 K t_s}{r d 10^8} \quad (38c)$$

The constant 1.2224 of equation 38c is about 0.1 of one per cent higher in value than 1.2211, as obtained in equation 5.

Equation 38c yields the same interlamination resistance as is obtained from equation 5, being based on the average stray loss rather than the desirable value obtained from the maximum stray loss of equation 8. Unfortunately, equation 38 does not call to the designer's attention immediately nor clearly that the interlamination resistance is a function of the square of the lamination width and the lamination thickness, although it shows that the resistance is a function of the square of the flux density and frequency.

Reference

1. INTERSHEET EDDY-CURRENT LOSS IN LAMINATED CORES, L. V. Bewley, Hillel Poritsky. AIEE TRANSACTIONS, volume 56, 1937, March section, pages 344-6.

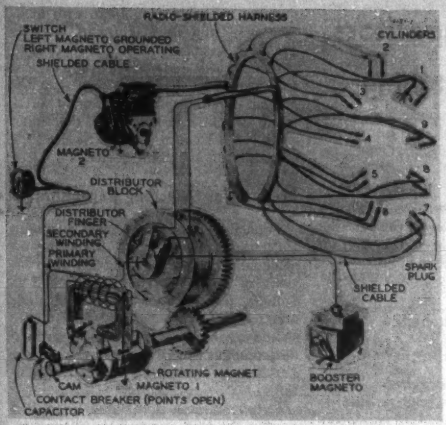

Figure 1. Schematic illustration of aircraft ignition system

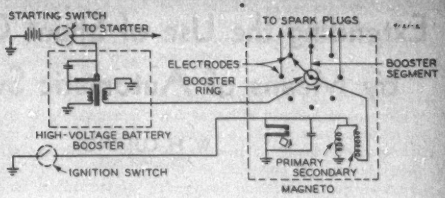

Figure 2. High-voltage battery booster circuit

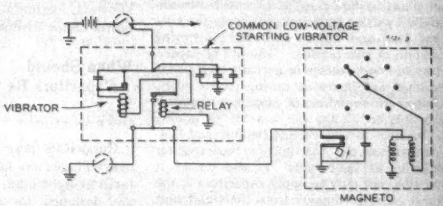

Figure 3. Common low-voltage starting vibrator circuit

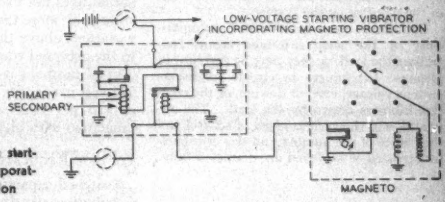

Figure 4. Low-voltage starting vibrator circuit incorporating magneto protection

laminated soft-iron core. A breaker mechanism is in series with the primary winding and battery for the purpose of producing rapid change of flux setting up high-voltage surges in the secondary winding. The secondary winding in turn connects to the magneto distributor segment.

The battery is connected to the booster coil through the engine-starter engaging switch on inertia starters or motor switch on direct cranking starters (see Figure 2). When the starter switch is closed, the booster coil is energized to provide high-voltage current at the spark plugs prior to coming-in speed. The booster coil fires but one plug in each cylinder; this is the plug giving the least detonation and is usually the front plug on radial engines. This plug usually is fired by the right magneto or the right side of a double magneto. Booster coils are not connected to both magnetos nor to both sides of a double magneto.

The main objection to high-voltage booster systems is the inherent disadvantage in that the trailing finger of the magneto must be placed so far back, to prevent jumping back at altitude, that the starting spark may occur anywhere from 30 to 60 degrees after top dead center. This difficulty has been overcome and correct timing of the starting spark obtained by boosting the main magnetos, thus dispensing with starter magnetos, or high-voltage coils, magneto booster rings and trailing segments. This method consists of using a separate induction coil (low-voltage starting vibrator) connected to the magneto primary winding, utilizing it as a transformer and supplying it with alternating impulses of the order of 150 volts (see Figure 3). It is made up of a coil wound on a soft-iron core connected in series with a breaker operated by magnetic action of the core. A relay is included, in series with and between the booster and magneto, to prevent magneto current feedback through the booster when the booster is not in operation.

A complete wiring diagram of a low-voltage starting vibrator is shown in Figure 3. A battery is connected to the magneto primary winding—through the breaker and vibrator coil. A circuit such as this has one drawback in that no protection is afforded the main magneto in instances when breaker contacts tend to "freeze." "Freezing" of breaker contacts results in high current flow, in some cases 40–45 amperes in a 24-volt system, due to low resistance value of vibrator and magneto windings. High current flow will cause demagnetization of magneto permanent magnets and burning of magneto primary winding. This difficulty has been overcome by using a system illustrated in Figure 4. The vibrator circuit here differs from the common unit in that the coil consists of a double winding having a common core and common ground. The primary winding has more turns than the secondary winding, so that, for a given magneto current requirement, a lesser amount need be interrupted through the primary winding. This is not the case in Figure 3. This feature contributes greatly to longer contact life, and, too, should the breaker contacts "freeze," no induction takes place, and current will flow through the primary winding to ground. Under these conditions no harm can be done to the magneto.

Earlier types of magnetos have magnets of low-coercive-force steel which would lose their magnetism if used with a low-voltage starting vibrator. Engine starting speed, hand cranking, kickback, and required spark retard for starting all have a bearing on use of low-voltage units in place of high-voltage type.

Oscillations in a vibratory system are very complex, involving the primary LC circuit, the secondary LC circuit and distributor-to-spark plug circuit. Calculations of a coupled circuit are difficult enough in an a-c case; they are more so in the transient case and practically impossible when spark gaps, nonlinear iron, and dielectric losses are combined with free oscillations.

Extending the Use of Shunt Capacitors by Means of Automatic Switching

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Synopsis: It generally is recognized that the kilowatt loading on distribution circuits or plant feeders may be increased substantially by using capacitors to supply the kilovar load and relieve the current-carrying system of this burden. The use of capacitors to boost voltage or actually to regulate voltage has increased during recent years. Automatic switching of capacitors makes it possible to obtain the benefits of adding capacitors to take care of the full load kilovars without the objection of excess capacitor kilovars at light loads. It also makes it possible not only to apply capacitors in the most effective manner from the standpoint of meeting power-factor limits established by the utility, but also to regulate voltage in the plant or on the system.

Capacitors may be switched automatically by the same switching means controlling the load, or they may be switched in response to changes in circuit conditions such as voltage, current flowing, or the reactive kilovars drawn by the load. The advantages of the various types of control and the choice of the number and size of capacitor steps to be switched are discussed fully.

THE wide acceptance of shunt capacitors and the desire to obtain the benefits of adding sufficient capacitor kilovars to meet the full-load kilovar requirements has resulted in a demand for equipment which will switch them automatically to avoid excessive leading kilovars or overvoltages at light loads. The automatic switching makes it possible to obtain the benefits of additional capacitor correction that otherwise would not be permitted. The effectiveness of shunt capacitors often can be increased by switching them "on" and "off" in accordance with changes in load. This is particularly true on circuits with widely varying loads where it is desired to maintain improved voltage conditions, or hold the current or kilovars supplied by the source to a minimum with variation in kilowatt loading. The demand for switching equipment increases as more and more capacitors are added to compensate, in whole or in part, for the kilovars demanded at full load. In general, capacitors should be switched to prevent overvoltages, to reduce line current, to keep the demand low in proportion to the kilowatt loading, or keep the over-all power factor within desired limits.

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When Should Capacitors Be Switched?

Overvoltage

Capacitors may be switched to avoid overvoltages on lamps, motors, and so forth at light load. Standard capacitors are designed for operation on circuits whose average voltage over a 24-hour period does not exceed the normal rated voltage by more than five per cent. The variations above the average may go up to the accepted standard limit of 115 per cent of normal rating for 230-, 460- and 575-volt capacitors or the standard limit of 110 per cent of normal rating for capacitors with higher voltage ratings.

Voltage Regulation

Switched capacitors can be located on distribution circuits or plant feeders beyond the voltage regulators to improve voltage regulation by reducing the current flowing in the feeders. This is accomplished without changing existing regulating equipment and lowers the IX and IR losses in the circuit.

Reduction of Power Costs

To maintain minimum cost of power purchased under certain rate schedules, capacitor kilovars should be varied to keep the power factor within certain limits or to keep the demand to a minimum with variation in kilowatt loading.

Avoid Objectionable Harmonics at Light Load

In a few cases it has been found desirable to switch capacitors "off" during light-load conditions because of the combination of objectionable harmonics and overvoltages. These cases are rare, but when they are encountered, it is usually more economical and satisfactory to switch the capacitors "off" automatically during light loads when they are not required than to apply a filter or wave trap.

The decision on whether or not the capacitors should be switched automatically depends upon the benefits expected, the size of the capacitor banks, the extent to which the kilowatt and kilovar load varies over a typical load period, and the variation of voltage with load. The first step in making an analysis usually is to make measurements of kilovars, kilowatts, and voltage over a typical load period to determine the capacitor kilovar requirements and then, if automatic switching is needed, to determine what type of control should be used for actuating the switching device.

Methods of Switching Capacitors

Capacitors may be switched manually with variations in load. Requiring an attendant to make the necessary observations of operating conditions such as voltage, power factor, kilovar demand, and so forth, this method of switching should be considered for those cases where an attendant can be assigned the specific duty of performing the switching operations.

In general, capacitors should be applied as near the load as possible. Therefore, if it is found desirable to switch capacitors with variations in load, one of the first things to consider is the distribution of the capacitors on the feeders and their connection directly to the motor terminals so that they may be switched "on" and "off" with the motor without additional switching equipment. In this connection, the capacitor kilovars switched with the motor switch should be selected to avoid excessive overvoltage due to self-excitation. It is difficult to determine how large the capacitor may be without causing excessive overvoltages unless the motor characteristic curves are available. The majority of motors will generate about 165 per cent normal rated voltage when disconnected from the line with a capacitor whose kilovar rating is equal to the motor horsepower rating. Some motors may generate higher voltages under these conditions. No overvoltage is encountered if the capacitor kilovar is not greater than the motor no-load kilovar.

In some instances it may be desirable to use a separate switch for the capacitor

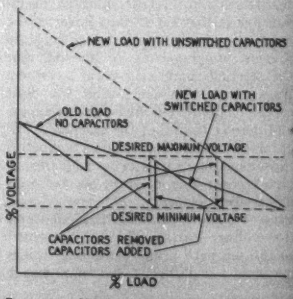

Figure 1. Kilowatt load increased 225 per cent by adding switched capacitors without increasing voltage regulation

which is controlled by the motor control. If the motors are small or if, due to load factors involved, it is not practical to switch the capacitors with the motors, then automatic switching equipment should be used with the capacitor.

If the load follows the same repetitive load pattern each week, then a time switch may be a practical means of initiating the switching operations. This type of device is not suitable for applications where the load fluctuates widely with a variable load cycle.

Capacitors also may be switched automatically in response to changes in load. There are three generally accepted methods of initiating the switching of capacitors automatically:

1. Voltage control—In response to changes in circuit voltage by means of a voltage-sensitive relay.

2. Current control—In response to changes in load current by means of a current-sensitive relay.

3. Kilovar control—In response to changes in reactive load by means of a kilovar-sensitive relay.

Voltage Control

The automatic switching of capacitors in response to changes in circuit voltage may be considered for applications where objectionable voltage deviations occur with varying loads. It is well known that capacitors will raise the general voltage level on a typical circuit.

To have a clear conception of voltage changes or voltage regulation, it will be helpful to remember that for all practical purposes the voltage drop can be determined from the kilowatt-load component flowing through the resistance of the circuit plus the kilovar component flowing through the reactance of the circuit. The voltage drop caused by the kilowatts is the product of the kilowatt load in amperes and the circuit resistance in ohms. The voltage drop caused by kilovars is the product of the kilovar load in amperes and the circuit reactance in ohms. The total voltage drop is the sum of the two. The voltage rise produced by the capacitor is the product of the circuit-reactance ohms and the change in kilovar-load amperes provided by the capacitor. The voltage change affected by switching a capacitor is the product of the circuit-reactance ohms and the change in kilovar-load amperes produced when the capacitor is switched. In calculation of voltage rise produced by the capacitor above an existing voltage level, the nonlinear variation of exciting kilovars drawn by motors, transformer, and so forth, should be given due consideration. If the voltage level is high, the exciting kilovar load may increase rapidly with increase in voltage and should be taken into account in arriving at the net kilovar load. It also should be remembered that the capacitor kilovar varies as the square of the voltage for a given rating. If the voltage level is moderate and steps are taken to permit only a small change in voltage, the nonlinear variation of exciting kilovars may be of no consequence and may be disregarded. In this case the voltage rise produced by the capacitor is the product of the circuit-reactance ohms and the capacitor current.

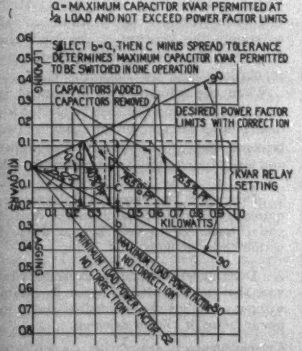
Q = MAXIMUM CAPACITOR KVAR PERMITTED AT ½ LOAD AND NOT EXCEED POWER FACTOR LIMITS
SELECT b = Q, THEN C MINUS SPREAD TOLERANCE DETERMINES MAXIMUM CAPACITOR KVAR PERMITTED TO BE SWITCHED IN ONE OPERATION
CAPACITORS ADDED
CAPACITORS REMOVED
DESIRED POWER FACTOR LIMITS WITH CORRECTION
KVAR RELAY SETTING
KILOWATTS
KILOVARS
LEADING
LAGGING
MINIMUM LIGHT POWER FACTOR WITH CORRECTION
NO CORRECTION
MAXIMUM LIGHT POWER FACTOR WITH NO CORRECTION

Figure 2. Curves showing relation between kilovars, kilowatts, and power factor, and how capacitors may be switched to keep power factor or kilovar demand within desired limits

The following steps are necessary to determine the amount of capacitors to be connected permanently and the number and size of capacitors to be switched to maintain satisfactory voltage conditions:

1. Determine light-load voltage with total capacitor kilovars connected.

2. If the light-load voltage with the total capacitor kilovars connected is objectionable, then determine the maximum capacitor kilovars permitted during light-load conditions without exceeding the upper voltage limit.

3. Determine maximum-size capacitor that can be switched in one operation or step without exceeding the permissible voltage change.

4. The total capacitor kilovars to be switched is the difference between the total capacitor kilovars required and the capacitor kilovars permitted during light-load conditions.

5. The minimum number of switching steps is the ratio of total capacitor kilovars to be switched to the maximum capacitor kilovars that can be switched at one operation without exceeding the permissible voltage change.

Example. Consider the case of an industrial plant at the end of a feeder where it is desired to increase the load from 442 kilowatts at 65 per cent power factor to 950 kilowatts at 65 per cent power factor without exceeding the current rating of the circuit or increasing the voltage regulation. Power is supplied from a substation over a 2,400-volt three-phase primary feeder consisting of 4/0 cable with equivalent spacing of 33.6 inches, to the 1,000-kva 2,400/460-volt plant transformer bank having 5.4 per cent reactance and 5.55 per cent impedance. The distance from the load center to the transformer bank is approximately 50 feet and from the transformer to the substation is one-half mile. The circuit impedance between the load and the substation as figured on a 2,400-volt base is as follows:

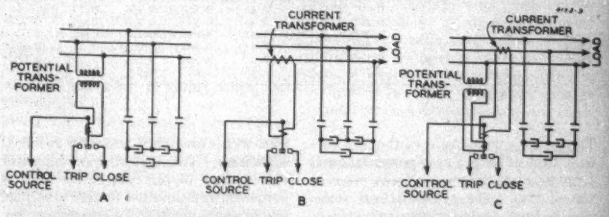

Figure 3. Three methods of automatically switching capacitors

A. Voltage control
B. Current control
C. Kilovar control

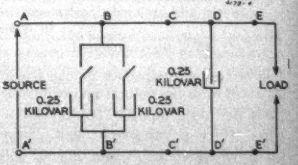

Figure 4. Circuit diagram showing location of load and capacitors referred to in Table I

Substation to transformer	$0.15 + j0.315$
Transformer	$0.073 + j0.31$
Transformer to load center	$0.013 + j0.131$
Total	$0.236 + j0.756$ ohm

The kilovars permitted when supplying 950 kilowatts without exceeding the 1,000-kva rating of the plant transformer is 310 kilovars ($\sqrt{1{,}000^2 - 950^2} = 310$).

Table I. Relation Between Power Factor, Kilowatts, Kilovars, and Kilovolt-Amperes for an Assumed Variation of Load Where Capacitors Are Located as Shown in Figure 4 and Switched at Predetermined Values of Load

Load Kilowatt	Capacitor B—B′	Kilovar D—D′	Conditions at E—E′			Conditions at C—C′			Load Increasing, Conditions at A—A′			Load Decreasing, Conditions at A—A′		
			Power Factor	Kilovolt-Amperes	Kilovar	Power Factor	Kilovolt-Amperes	Kilovar	Power Factor	Kilovolt-Amperes	Kilovar	Power Factor	Kilovolt-Amperes	Kilovar
1.0	0.50	0.25	0.707	1.415	1.0	0.80	1.25	0.75	0.97*	1.03	0.25*	0.97*	1.03	0.25
0.9	0.50	0.25	0.707	1.275	0.9	0.81	1.11	0.65	0.966	0.912	0.15*	0.936	0.91	0.15
0.9	0.50	0.25	0.707	1.13	0.8	0.824	0.972	0.55	0.998*	0.802	0.05*	0.998*	0.802	0.05
0.75	0.50	0.25	0.707	1.06	0.75	0.832	0.902	0.50	1.00	0.75	0.0	1.00	0.75	0.0
0.75	0.25	0.25	0.707	1.06	0.75	0.832	0.902	0.50	0.948*	0.792	0.25			
0.7	0.50	0.25	0.707	0.99	0.7	0.84	0.833	0.45				0.97ℓ	0.702	0.05ℓ
0.7	0.25	0.25	0.707	0.99	0.7	0.84	0.833	0.45	0.961*	0.728	0.20*			
0.65	0.50	0.25	0.707	0.92	0.65	0.85	0.764	0.40				0.988ℓ	0.659	0.10ℓ
0.65	0.25	0.25	0.707	0.92	0.65	0.85	0.764	0.40	0.974*	0.668	0.15*	0.974*	0.668	0.15*
0.6	0.25	0.25	0.707	0.85	0.6	0.863	0.96	0.35	0.986*	0.608	0.10*	0.986*	0.608	0.10*
0.5	0.25	0.25	0.707	0.708	0.5	0.893	0.56	0.25	1.00*	0.50	0.0	1.00	0.50	0.0
0.5	0.0	0.25	0.707	0.708	0.5	0.893	0.56	0.25	0.894*	0.56	0.25*			
0.45	0.25	0.25	0.707	0.637	0.45	0.913	0.494	0.20				0.993ℓ	0.454	0.05ℓ
0.45	0.0	0.25	0.707	0.637	0.45	0.913	0.494	0.20	0.913*	0.494	0.20*			
0.4	0.25	0.25	0.707	0.566	0.4	0.935	0.428	0.15				0.97ℓ	0.413	0.10ℓ
0.4	0.0	0.25	0.707	0.566	0.4	0.935	0.428	0.15	0.936*	0.427	0.15*	0.936*	0.427	0.15*
0.3	0.0	0.25	0.707	0.425	0.3	0.986	0.304	0.05	0.986*	0.304	0.0*	0.986*	0.304	0.05*
0.25	0.0	0.25	0.707	0.354	0.25	1.00	0.25	0.0	1.00	0.25	0.0	1.00*	0.25	0.0

* Lagging. ℓ Leading.

The reactive component of the 950 kilowatt load at 65 per cent power factor is 1,110 kilovars (kvar = tan $\theta \times$ kw = $1.17 \times 950 = 1{,}110$). The expected load variation is from one fourth to full load or $237\frac{1}{2}$ to 950 kw. If the measured voltage at $237\frac{1}{2}$ kw is 101 per cent and the permissible voltage change is ± 2.6 per cent of normal then the size and number of capacitors can be determined, neglecting the nonlinear variation of exciting kilovars, from the following formula:

$$\text{Per cent voltage rise produced by capacitor} = \frac{\text{capacitor kilovars} \times \text{circuit reactance in ohms}}{10 \times (\text{line kilovolts})^2}$$

The 800-kilovar capacitor at one fourth load will raise the voltage approximately $10\frac{1}{2}$ per cent $(800 \times 0.756)/10 \times 2.4^2 = 10\frac{1}{2}$, which is excessively high. Since the voltage is one per cent above the mean level without capacitors at one fourth load, then the maximum capacitor kilovar permitted should not increase the voltage more than 1.6 per cent (2.6 − 1.0). The capacitor permitted at one fourth load is $1.6 \times 2.4^2 \times 10/0.756 = 122$ kilovars. Use the nearest standard rating of 120 kilovars.

Since it is desired to keep the voltage within ± 2.6 per cent of normal, the capacitor selected should not change the voltage by more than 5.2 per cent minus a margin or tolerance which will prevent the possibility of hunting. If a margin of 0.3 per cent is chosen at both the upper and lower limits, then the capacitor kilovar selected should not change the voltage more than 4.6 per cent. The maximum size capacitor to be switched in one step is 350 kilovars $(4.6 \times 2.4^2 \times 10)/0.756 = 350$, and the minimum number of switching steps is two since $(800 - 120)/350 = 1.94$.

Figure 1 shows graphically the voltage regulation with variation in load for the old load without capacitors and the new load with unswitched and with switched capacitors. The 120-kilovar capacitor representing 15 per cent of the total is permanently connected to give a voltage rise of approximately 1.6 per cent at one fourth load. The remaining 680 kilovars is divided into two equal groups of 340 kilovars and switched automatically in response to voltage to keep the voltage within the desired limits. Each 340-kilovar capacitor switched changes the voltage approximately 4.5 per cent.

Kilovar Versus Current Control

When capacitors are connected to a well-regulated bus, the voltage regulator or other devices usually will keep the voltage within satisfactory limits or attempt to do so independently of the amount of capacitor kilovars applied. Circuit voltage, therefore, does not reflect truly the need for capacitors and, if the capacitors are to be switched, other methods of detecting the capacitor requirements should be used.

If sufficient capacitor kilovars are added to supply the lagging reactive kilovars at full load, then it may be desirable to switch the capacitors with variation in load to obtain maximum benefits by keeping the demand and losses to a minimum or to avoid the possible penalty of excessive leading power factor during light loads. In some instances the kilovars supplied by the capacitor make it possible for the regulating equipment to keep the voltage up to a satisfactory level at full load and in such cases the voltage at light load is very likely to be excessive unless capacitors are switched.

One method to consider is that of switching the capacitors in relation to line current. This is satisfactory and preferred provided the load power factor remains relatively constant with variation in kilowatt loading or the power factor of the load varies in a predictable manner with a variation in kilowatt loading. However, if the load power factor does not vary in a predictable manner, then the capacitor should be switched in response to the load kilovar requirements. When the latter type of control is used, it is not necessary for the load power factor to have a definite relationship with kilowatt loading. In cases where either type of control can be used, the existing physical circuit arrangement may dictate the type to be selected.

Kilovar Control

The kilovar method of control should be used to switch capacitors when the load voltage is regulated and the load power factor varies in an unpredictable manner with variation in kilowatt loading. It often may be used in conjunction with existing voltage regulators to improve voltage regulation. In some instances the existing voltage regulators may not provide satisfactory voltage regulation but when switched capacitors are added to supply the kilovars of the load, the regulators then may provide satisfactory regulation.

When the kilovar type of control is used, the following steps are suggested for determining the amount of capacitors to be connected permanently and the number and size of capacitors to be switched:

1. Determine the capacitor kilovars required at light load to maintain desired power factor or to keep kilovar demand within desirable limits.

2. Determine the maximum capacitor kilovars that can be switched in one operation without exceeding the permissible change in power factor or kilovar demand.

3. The difference between the total capacitor kilovars proposed and the capacitor kilovars permitted duirng light-load conditions determines the total capacitor kilovars to be switched.

4 The minimum number of switching steps is the ratio of the total capacitor kilovars to be switched to the maximum kilovars that can be switched in one operation and stay within the power-factor limits or kilovar-demand limits.

Example. Consider the case of an industrial plant where it is desired to improve the full-load power factor from 70.7 per cent to 97 per cent and thereby reduce the demand approximately 27 per cent or from 1.41 kva per kilowatt to 1.03 kva per kilowatt. The capacitor required to do this is 0.75 kilovar per kilowatt. The expected kilowatt-load variation is between one-fourth and full load and the maximum variation of load power factor without correction is between 62 per cent and 80 per cent lagging. If it is desired to add correction to keep the power factor between 90 per cent lagging and 90 per cent leading for all load conditions, then the boundaries are outlined which will permit the selection of maximum capacitor kilovar at light load.

The kilovars at light load and at maximum uncorrected power factor plus the leading kilovars permitted at light load without exceeding the permissible leading power factor determines the maximum capacitor kilovars permitted at light load or $0.187+0.12=0.309$ kilovar. Once the permanently connected capacitor is determined, this together with the previous boundaries permits the selection of the maximum capacitor kilovars that may be switched automatically in one operation. If 0.3 capacitor kilovar is connected permanently, determine the kilowatt loading at which the 0.3 capacitor kilovar will improve the power factor from 62 per cent to 90 per cent. See Figure 2, line $b=0.3$ kilovar at 0.377 kw. The capacitor kilovars required to improve the power factor at this loading point from 90 per cent to unity plus the leading kilovars permitted at light load is 0.305 kilovar. See Figure 2, line c. This determines the maximum capacitor kilovars that can be switched and stay within the power-factor limits. Since the microfarad tolerances of shunt capacitors are usually in the plus direction, and also since the kilovars vary as the square of the voltage, the kilovar relay should always be adjusted for a greater spread than the kilovar rating of the capacitor by a margin sufficient to avoid hunting. If the capacitor kilovars are reduced to 75 per cent of its original calculated value to provide this margin, then the normal capacitor rating should not exceed 0.229 kilovar. The minimum number of automatically switched capacitor steps is $(0.75-0.3)/0.229=1.94$, therefore, the 0.45 capacitor kilovar should be divided into two equal groups of 0.225 kilovar. The kilovar relay may be adjusted to switch the capacitors "on" at 0.175-kilovar lagging with increase in loading and switch capacitors "off" at 0.125-kilovar leading with decrease in loading.

The curves in Figure 2 show power-factor boundaries with and without correction. The two broken horizontal lines show the kilovar relay settings for switching the capacitors "on" and "off" to keep the power factor at all times within 90 per cent lead or lag for load variation of one-fourth to full load. For the one particular variation of loading illustrated, the permanently connected 0.3-kilovar capacitor changed the power factor at one-fourth load from 80 per cent lag to 90 per cent lead. The load increases at a minimum power-factor slope of 40 per cent until the first automatically switched capacitor is added when the reactive reaches 0.175 kilovar. The 0.225-kilovar capacitor changes the power factor to slightly leading and the load increases at a power-factor slope of $76\frac{1}{2}$ per cent until the second automatically switched capacitor is added when the kilovar reaches 0.175. The second 0.225-kilovar capacitor changes the power factor to slightly leading and the load increases at a power-factor slope of $76\frac{1}{2}$ per cent until full-load conditions are reached. On decrease of load the capacitors are switched "off" in the reverse order when the leading reactive reaches 0.125 kilovar as indicated by the broken extended lines. The loading may increase or decrease at different power-factor slopes than those shown and the power factor will be maintained within the desired limits so long as the operating conditions are within the boundaries outlined.

If the full load in this case happened to be 1,000 kw, then a total of 750 capacitor kilovars is required, 300 kilovars to be connected permanently and the remaining 450 kilovars to be switched in two equal steps of 225 kilovars.

Figure 3. Single-step kilovar control assembled with outdoor capacitor rack showing kilovar relay, two-element time-delay relay, and control switch

Current Control

Current control should be considered for switching capacitors where the voltage is well regulated and the power factor of the load remains substantially constant with variation in kilowatt loading or if the power factor of the circuit varies in a predictable manner with variation in kilowatt loading. If in some instance the existing voltage regulators do not give satisfactory voltage regulation, capacitors may be added and switched in response to current to obtain satisfactory voltage regulation in combination with the regulators.

In analyzing the application of capacitors automatically switched in response to current there are always at least two power factors involved and in some instances more. To illustrate how some of the various circuit conditions should be analyzed when more than two power factors are involved, a diagram and tabulation has been prepared. The values shown in Table I are based on the following assumptions:

1. The power factor at point E–E remains at 70.7 per cent lagging for the maximum load variation of 25 to 100 per cent.

2. One 0.25-kilovar unswitched capacitor is located at point D–D to improve the power factor at E–E to unity at minimum load of 25 per cent.

3. Two 0.25-kilovar switched capacitors are located at point B–B to improve the circuit power factor at E–E to 97 per cent lagging at full load. One capacitor to be switched on at 50 per cent kw load and off at 40 per cent kw load and the second capacitor to be switched on at 75 per cent kw load and off at 65 per cent kw load.

The number and size of the capacitor can be determined in a similar manner to that described for the kilovar control. If more than one switched capacitor is required, a separate current control is required for each capacitor switch. These can be adjusted for different current values to give the same results as multistep kilovar control.

Equipment Required

The automatically switched capacitor station consists essentially of the capacitor, the capacitor switch, the automatic control and instrument transformers, and control source.

The Capacitor

The capacitor usually will be one of the standard ratings and types of mounting

Figure 6. A 1,440-kilovar three-phase 460-volt capacitor divided into four 360-kilovar indoor equipments with electrically operated air circuit breakers and four-step automatic control

which is suitable for the particular location and circuit requirements.

Capacitor Switch

The capacitor switch should be equipped with overcurrent trip devices unless other overcurrent protection is provided. If the switch is equipped with overload and fault-current protection, then it should also have a lockout feature to prevent the switch from closing, if tripped from overcurrent, until the lockout device is reset manually. Of course, if the switch does not have overcurrent trip devices, then no lockout feature is required and the master breaker or line fuses should provide the overcurrent protection.

The capacitor switch should be suitable for repetitive duty and should be selected to have the correct rating as to voltage, continuous current, momentary current, and interrupting ability. Contactors with line fuses or overload attachments may be considered for switching small low-voltage capacitors where the fault current and momentary inrush current does not exceed the maximum momentary rating of the contactor. Oil-immersed contactors may be used on small high-voltage capacitors on a similar basis.

Electrically operated circuit breakers generally are used for switching the larger size capacitor equipments. The breaker should, of course, be selected to have the proper voltage, continuous current, momentary current, and interrupting ability. On the very large banks of the higher voltage ratings the possibility of restriking when opening the circuit to the capacitor is greater and this should be taken into consideration when selecting a breaker.

It is often necessary to have current transformers in the circuit to the capacitors as a means of energizing breaker overcurrent trips. If the transient inrush current is high when the capacitor switch is closed, then sufficiently high voltage may appear across the secondary winding to necessitate a protective device to limit the voltage to a safe value and avoid damaging the insulation in the secondary of the current transformer circuit. This is particularly true on large capacitor banks closely coupled.

Automatic Control

The automatic control for switching capacitors usually consists of a master element, time-delay relays, auxiliary devices, and control switch. A voltage-sensitive relay, current-sensitive relay, or kilovar-sensitive relay may be selected as the master element for initiating the switching operations. The time-delay relays will allow sufficient time to prevent unnecessary switching operations, caused by momentary disturbances on the power circuit. The time-delay desired usually is not critical, but in the interest of keeping the transient current to a minimum, sufficient time delay should be chosen between the opening and closing of the capacitor switch to allow the discharge device to drain off a substantial part of the stored energy before the next switching operation. The auxiliary relays respond to the request of the master element and time-delay relay combination to close or open the capacitor switch. Control switches usually are desired to permit opening and closing of each capacitor switch by manual operation of its control switch or have the capacitor switch open and close in response to the master element.

Instrument Transformers and Control Source

A potential transformer is required for voltage control, a current transformer is required for current control and both current and potential transformers are required for kilovar control. See figures 3A, 3B, and 3C for their positions in circuit. In all cases a single-phase control source is required. Suitable instrument transformers and control source may or may not be available at the proposed capacitor location.

Description of Operation

Single-Step Control

If the control switch is in the automatic position and one set of the master-element contacts close, indicating that capacitor kilovars are required, this will energize the closing element of the time-delay relay. If the initial cause is not a temporary disturbance, then the master-element contacts will remain closed until the time-delay relay contacts have closed energizing the closing mechanism of the capacitor switch. The capacitor switch will then close and connect the capacitor to the circuit.

If with the capacitor connected to the circuit one set of the master-element contacts close, indicating that the capacitor correction should be removed, this energizes the tripping element of the time-delay relay. If the master-element contacts remain closed for the time required for the time-delay tripping contacts to close, then the capacitor-switch tripping device will be energized opening the capacitor switch and disconnecting the capacitor from the circuit.

Multistep Control

The multistep control operates in a manner similar to the single-step control except that it is arranged to switch two or more groups of capacitors selectively and automatically by means of a time-delay relay for each separate group in combination with auxiliary contacts on the capacitor switches. The time-delay relays operating in conjunction with the auxiliaries of the capacitor switches set up the circuits to close or open the capacitor switches in a definite sequence responding to the master element with time delay between switching operations.

Conclusions

1. The usefulness of shunt capacitors can be increased by switching them automatically.

2. The benefits of adding capacitors to supply kilovars up to full-load conditions can be obtained, if automatic switching is applied to remove the objectionable leading kilovars at light load.

3. The type of control to use and the size and number of automatically switched capacitors steps required to do a particular job can be determined when the operating conditions and requirements are known.

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Magnesyn Remote Indication

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REMOTE indication is, in general, the transfer of information or intelligence from one point to a remote point in a semipermanent form which may be visually observed. A variety of means can and have been used to accomplish such a purpose. Information can be sent from one place to another simply by moving a long string or cable, rotating a long flexible shaft, changing pressure in a hydraulic or pneumatic line, changing the characteristics of an electric circuit, as well as by methods involving thermal and optical devices. The fields of telemetering and visual recording are well-known branches of remote indication. Automatic control systems and computing mechanisms depend on remote indication for their source of intelligence.

As aircraft have increased in size and complexity, improved methods of remote indication have become most essential. Practically all information concerning the performance and conditions of engines and ship that is brought to the attention of the pilot comes to his instrument panel by means of remote indication. Relatively large distances exist between pilot and flight-instrument sensing elements, between flight engineer and engines, and between navigator and compass. Pneumatic and hydraulic methods are still most efficient for some functions, but a majority of indications are carried out electrically on modern aircraft. In many cases electric systems can offer a saving in weight, simplicity of installation and maintenance, greater accuracy, better interchangeability of components, reduction in military combat hazard, and a somewhat more inexpensive unit. In some cases electric systems have been the only practical way of remotely indicating a particular function.

Electrical methods of remote indication, as used on aircraft, can be divided into four general groups. D-c systems, using a variable resistance for a transmitter and a voltmeter for an indicator, were probably the first form to be used. This method is still widely used for temperature indication where the variable-resistance transmitter becomes a temperature "bulb," utilizing the inherent change in resistance with temperature of an electric conductor.

Autosyns* have been extensively used on aircraft since 1932 as an a-c electric remote-indicating system similar to the self-synchronous motors used in marine order signal systems and many industrial applications. A transmitting Autosyn which has a rotor mechanically actuated by the function to be indicated is electrically wired to one or more similar Autosyns as indicators with pointers and dials. Every motion of the transmitting rotor is reproduced as a motion of the indicating pointer. The prime mover may be any of the engine-pressure functions, liquid-level functions, or position functions of any movable part on the aircraft.

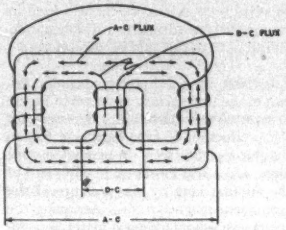

Figure 1. Frequency doubler

A third class of remote indicating instruments are the d-c Autosyns. Operation is analogous to the a-c Autosyn, where the a-c field is replaced by a d-c field. The transmitter is a continuous circular resistance with three equally placed taps contacted on a diameter by a direct voltage. When connected to an indicator similarly wound with a continuous tapped winding on a magnetic iron core, a d-c field will be set up across a diameter of the indicator corresponding to the diameter of the transmitter that is contacted by the d-c voltage. The rotor of the indicator can then be a permanent magnet which will align itself with the indicator field.

A more recent development, which has become well suited to the requirements of aircraft remote indication, is the Magnesyn system. Originally applied to the problem of remote compass operation, it is equally adaptable to most of the functions which are remotely indicated on aircraft. It retains the advantages of a simple indicating unit, as used in the d-c Autosyn system, but utilizes a transmitting unit that is equally simple. The Magnesyn system is a-c operated and uses identical units for transmitter and receiver. In each case, the stator is a toroidally wound tapped coil on a laminated magnetic core, and the rotor is a permanent magnet. Rotation of the transmitter rotor causes corresponding rotation of the indicator rotor.

The preceding four systems are the only ones that have been used in quantity on aircraft. Other electric remote-indicating systems that have been considered are the distometer and the inductance bridge.

In order to understand the somewhat involved magnetic circuit of the Magnesyn, it is perhaps worth while to consider some of the chronological steps in its development. A well-known phenomenon basic to the operation of the Magnesyn is the production of harmonic voltages in a saturated reactor. Such a reactor, shown in Figure 1, is often used as a frequency doubler. An *E-I* lamination core of a magnetic material that saturates abruptly is wound with coils on the outside legs, series aiding, and a separate coil on the center leg. If a sufficiently large alternating current is passed through the outside windings, the magnetic path made up of the outside legs and top and bottom sections will be alternately saturated and unsaturated with magnetic flux twice every cycle. When direct current is passed through the center winding, the magnetic path presented to its field is made up of the two outside legs in parallel. Consequently the magnetic path of the d-c circuit is varying in permeability twice for each cycle of alternating current on the outside legs. This means that the flux passing through the d-c leg will vary from a maximum to a minimum twice for each a-c cycle, inducing a voltage in the d-c winding at even harmonic frequencies of the exciting voltage. The a-c circuit on the outer legs is acting as a "gate" on the amount of flux produced by the d-c field.

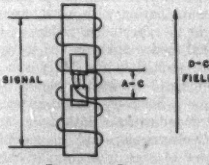

Figure 2. Flux gate

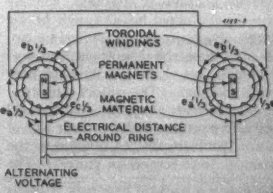

Figure 3. Magnesyn transmitter and receiver

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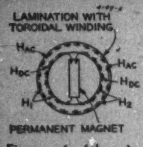

Figure 4 (above). Magnesyn magnetic circuit

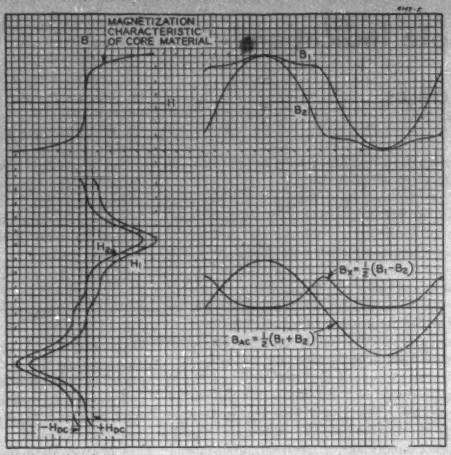

Figure 5 (right). Flux densities and corresponding magnetizing force

By replacing the field from the d-c winding by a permanent-magnet field, or even by the earth's magnetic field, the same principle of operation will apply. Early forms of a unit that operated in the earth's field were called "flux gates".* Construction of this form of frequency doubler is shown in Figure 2. An a-c winding on a portion of a strip of magnetic material serves to saturate the metal twice every cycle, thereby providing a path of variable permeability. Flux produced in the strip by the earth's field will then vary twice each cycle with the varying permeability, which, in turn, will produce an even harmonic voltage in a second winding around the strip. This action is basically the same as that of the original frequency doubler.

A further step in development was the idea that if fundamental flux in combination with a unidirectional field would produce an even harmonic flux in the aforementioned devices, then a fundamental flux in combination with even harmonic flux might be expected to produce a unidirectional field. Such proved to be the case and resulted in the Magnesyn system. Figure 3 shows the elements required for a Magnesyn transmitter and receiver or indicator. Both units can be identical electrically and magnetically. The stator of each is a circular core of magnetic material around which is placed a single continuous toroidal winding which is connected to a source of a-c voltage. Each winding is divided by two taps into three equal sections, and corresponding taps of the two units are connected together. The rotors are two-pole permanent magnets, magnetized along a line perpendicular to their axis of rotation, and are free to revolve in the centers of their respective stators. The Magnesyn is again a frequency doubler supplied by a unidirectional field from its rotor and presenting a variable-permeability path to this field because of the a-c flux produced by the winding.

By first considering the magnetic circuit of the transmitter, as shown in Figure 4, some of the relationships necessary for the production of even-harmonic flux in the stator can be seen. A magnetomotive force, H_{d-c}, will be set up in each half of the annular core by the presence of the permanent-magnet rotor. Assuming the core to be a homogeneous material, symmetrical in shape and concentric to the magnet, the reluctance of the two paths will be the same and H_{d-c} will be equal in the two halves of the ring.

When the transmitter winding is connected to a source of sine wave alternating voltage, the current drawn will produce an alternating magnetomotive force, H_{a-c}, which will be considered at a specific time to have a clockwise direction in the core. With respect to this exciting magnetomotive force, H_{a-c}, the unidirectional magnetomotive force is positive in one half of the core and negative in the other half. Then the total magnetomotive force in one half is

$$H_1 = H_{a-c} + H_{d-c} \tag{1}$$

and in the other half is

$$H_2 = H_{a-c} - H_{d-c} \tag{2}$$

A typical relationship between flux density produced in the core and magnetomotive force set up in the core is shown as the magnetization curve in Figure 5. By projecting a time cycle of H_1 and H_2 on this characteristic, the corresponding time cycles of flux densities B_1 and B_2 in each half of the core may be obtained. Flux density B_1 is made up of two components, B_{a-c} produced by the exciting voltages which is the same in both halves of the core, and an additional flux density B_x which exists because of the presence of H_{d-c}, combined with H_{a-c}, or

$$B_1 = B_{a-c} + B_x \tag{3}$$

Likewise, the flux density in the second half of the core

$$B_2 = B_{a-c} - B_x \tag{4}$$

From equations 3 and 4

$$B_{a-c} = {}^1/_2(B_1 + B_2) \tag{5}$$

and

$$B_x = {}^1/_2(B_1 - B_2) \tag{6}$$

The time relationships of B_{a-c} and B_x are shown in Figure 6, where it is clear that B_x is an even-harmonic function of B_{a-c} with a major second-harmonic component. Because voltage is induced in a winding surrounding a piece of magnetic material proportional to the rate of change of flux density in the material, component voltages E_{a-c} and E_x will be induced in the transmitter stator winding by B_{a-c} and B_x as shown in Figure 6. Total voltage induced by the axis of the magnet poles on the rotor then will be

$$E_1 = E_{a-c} + E_x \tag{7}$$

and in the other half will be

$$E_2 = E_{a-c} - E_x \tag{8}$$

The sum of E_1 and E_2 or $2E_{a-c}$ is equal to the impressed a-c voltage.

If we refer to Figure 3, the proportion of even-harmonic voltage appearing in each of the three sections of winding will depend on the position of the rotor. Figure 7 shows the relative amounts of this component voltage in each section as the magnet is rotated through 360 degrees. The fundamental component of voltage in each section, of course, is independent of magnet position and is equal to one third of the total applied voltage.

If taps on the transmitter are connected to the corresponding taps on the receiver stator, omitting the receiver rotor magnet for the moment, and both coils are sup-

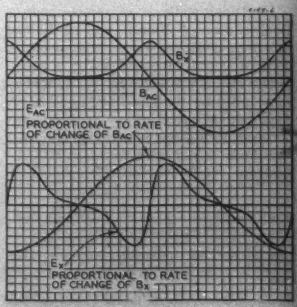

Figure 6. Flux density and voltages in the Magnesyn

* Flux Gate is a registered trade-mark of Bendix Aviation Corporation.

plied from the same a-c source, there will be no flow of fundamental current between the two units, because the voltages at the taps of each are at the same fundamental potentials. However, because there are even-harmonic voltages present in each section of the transmitter but none in a receiver with no magnet, there will be a flow of even-harmonic currents between the two coils. This flow of current effectively lowers E_x at the transmitter to some value, E_x', at each instant of time, and produces the same voltage, E_x', in the receiver winding in a corresponding position with respect to the three sections of winding.

It is difficult to obtain the actual value of E_x', but the action of the Magnesyn system can be none the less faithfully followed if E_x' is considered to be the same as E_x, which is the same as saying that B_1 and B_2 in the transmitter core are unchanged when the receiver stator is connected. Because the voltages in the receiver-stator winding have to be the same as those in the transmitter winding as a result of their interconnection, the flux densities in the receiver core must have the same rates of change. This means that B_1' and B_2' in the receiver must have the same time-cycle wave shape as B_1 and B_2 in the transmitter. Figure 8 shows B_1 in the transmitter with its associated H_1 followed by an assumed B_1' in the receiver with a time integral of zero and the H_1' in the receiver that would be required to produce the assumed B_1'. Such an assumption obviously presumes the presence of an effective unidirectional magnetomotive force in the receiver core which is impossible, inasmuch as there is no source of direct current anywhere in the system, nor is there any unidirectional field applied at the receiver. This delimits B_1' in the receiver to such a value that the time integral of H_1' in the receiver is zero, which in turn requires an effective unidirectional component of flux density to be produced in one half of the receiver core. A similar argument will show that a corresponding unidirectional flux-density component exists in the other half of the receiver core. Therefore, an effective unidirectional field will exist across a diameter of the receiver core, corresponding to the diameter in the transmitter in line with the rotor magnet poles. As the

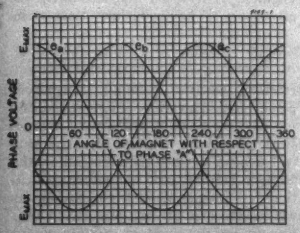

Figure 7. Phase-voltage variation

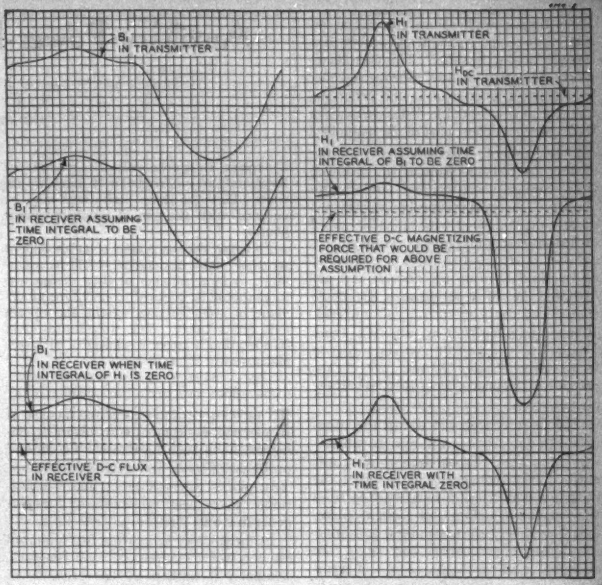
B1 IN TRANSMITTER
H1 IN TRANSMITTER
Hdc IN TRANSMITTER
H1 IN RECEIVER ASSUMING TIME INTEGRAL OF B1 TO BE ZERO
B1' IN RECEIVER ASSUMING TIME INTEGRAL TO BE ZERO
EFFECTIVE D-C MAGNETIZING FORCE THAT WOULD BE REQUIRED FOR ABOVE ASSUMPTION
B1 IN RECEIVER WHEN TIME INTEGRAL OF H1 IS ZERO
EFFECTIVE D-C FLUX IN RECEIVER
H1 IN RECEIVER WITH TIME INTEGRAL ZERO

Figure 8. Development of poles in the Magnesyn indicator

transmitter rotor is turned, the effective unidirectional field in the receiver stator will turn likewise.

If a permanent-magnet rotor is introduced at the receiver, a restoring torque gradient will make it align itself in the unidirectional field at the receiver. When it is in line with this field, exactly the same even-harmonic voltages will be induced in both transmitter and receiver coils, and the flow of even harmonic currents will cease. Rotation of the magnet in one unit then will cause corresponding rotation of the magnet in the other unit, and, since they are identical, either unit can act as a transmitter.

Because of the nature of the parts involved, the Magnesyn is an inherently simple device to fabricate. All laminations can be annular-ring punchings from sheet metal. The windings are readily adapted to an automatic machine operation. A round disk magnet is used for the rotor and the entire rotor assembly is no more than this magnet pressed on a suitable shaft. In practice, an additional annular core of magnetic material is placed around the outside of the stator serving the dual functions of a return path for even-harmonic flux to the stator and a magnetic shield against extraneous magnetic fields that may be present near the unit.

Perhaps the most outstanding feature of the Magnesyn system is the extremely low reaction torque on a prime mover. In any system the torque gradient of the prime mover must be sufficiently large to mask any friction or error torque gradients in either transmitter or receiver. Any friction torque of brushes or sliding contacts, as well as the bearing friction of rotor weight, must be overcome. Magnesyns have no source of friction except bearings and with jeweled pivots supporting a total rotor weight of the order of one gram, this source of friction is negligible to the most sensitive prime movers. Error torques likewise can be kept to a low value without excessively involved assembly techniques.

Some applications of remote indication in aircraft require the transmitting unit to be installed at a point of extremely high vibration. The construction of a Magnesyn can be modified to make it admirably suited to this requirement. The stator, associated lead wires, and electric connector can be molded literally into one solid unit. The rotor can be mounted on a rugged shaft, with suitable bearings to withstand anticipated vibration. It is even possible to mount the magnet on the prime mover directly and mount a molded Magnesyn stator concentrically to the prime-mover shaft. Such units have been constructed that are waterproof, dirtproof, and oilproof, and that withstand temperatures from −100 to +200 degrees centigrade, with sustained vibration of 100 gravity in any direction. There is no possibility of wear external to the prime mover and no hazard of sparking contacts in an explosive atmosphere.

For certain applications, it is not necessary to have the transmitters and indicators physically the same. This permits remote indication of any moving member by placing a magnet on it and providing a stator at a reasonable distance away in the most convenient part of the assembly.

Some general characteristics of the system are freedom from errors resulting from voltage variation and temperature changes. Accuracy can be maintained at any desired level with suitable choice of transmitter components. Transmitters can be constructed to drive any number of receivers. Units for aircraft use are operated at 26 volts from a 400-cycle source and draw about 1.5 volt-amperes. When operated from an inverter, these Magnesyns will perform satisfactorily on frequencies between 150 and 1,200 cycles, provided the ratio of frequency to voltage is maintained between 13 and 17.

The most widespread use of the Magnesyn to date has been in remote-indicating compasses. In modern combat aircraft it has been essential to place the compass element in a location free from the magnetic effects of armor plate, machine guns, turrets, engines, and other interfering components, and bring the compass heading to the pilot and navigator by remote indication. A single magnet mounted in a compass float serves both the purposes of aligning itself in the earth's field and acting as the rotor of a Magnesyn transmitter. Below the liquid cavity containing the compass float is a Magnesyn stator. This stator is connected to a receiver, and the compass heading is reproduced by a pointer on a dial. No moving parts are added to a conventional magnetic compass.

A class of flight instruments, including air speed, rate of climb, and altitude, has been successfully remotely indicated with the Magnesyn system. These prime movers, in general, are too weak to operate other systems. Practical trailing "bombs" containing these flight-sensing elements have used Magnesyn indication. Remotely operated weather instruments have incorporated the Magnesyn system to advantage.

For indication of the position of various moving members, such as wheels, a variety of flaps, bomb-bay doors, and so on, the shockproof construction type of Magnesyn is well suited. Vibration, dirt, water, and ice have little effect on the molded unit. A particular application where the Magnesyn has stood up remarkably well, is the indication of propeller pitch. Here the position transmitter is mounted in the hub of a propeller and subjected to extreme vibration.

Fuel-level and fuel-flow instrumentation in general presents the requirement that the electric system be external to any cavity containing gasoline vapors as a safety precaution. Most systems accomplish this by having the prime mover in the gasoline drive a magnet which, in turn, drives a follower or slave magnet outside the compartment. By using a Magnesyn stator in place of the slave magnet, the transmitter is complete with no additional equipment.

The development, method of operation, and some features of the Magnesyn have been described with a comparison of other existing electric systems. Magnesyns can be used in a variety of remote-indicating devices, some of which were impractical previously. Future developments will depend on new requirements in the aircraft industry and potential applications in industrial instrumentation, as well as the ever-present problem of continuous improvement in existing equipment.

Auxiliary-Power-Plant Requirements

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Synopsis: Designers of electrical equipment for aircraft are confronted with many limitations. Some of these limitations may be nullified with the use of auxiliary power plants.

To cover various phases of application a series of engine-generators would be necessary. A large number of their design features should be adapted to each type of airplane in order to save weight and obtain best performance. This necessitates close co-operation between designers of the component parts of the airplane.

IN developing and extending the use of electric equipment for aircraft, designers have been faced with the eternal problems of space and weight limitations. Two places where a great many limitations have been encountered are at generator and battery.

In most cases generators are mounted on accessory sections of main engines. Diameter is limited by the presence of other accessories, and overhang is limited by the strength of the mounting flange. Another undesirable feature, which has precluded the use of alternators, is the wide speed range of the drive.

Batteries, as a source of auxiliary power, have been a millstone around the necks of designers. With the airplane on the ground the accessory system is almost useless unless ground power units are available. Radio and other accessories can be operated only momentarily without reducing the battery charge to the extent that the main engines cannot be started.

Generator designers have done an excellent job in recent years. They have succeeded in multiplying the output of generators several times without exceeding the rigid space and drive limitations. Although we may expect further development, it is not likely that it will be so rapid.

Batteries also have been improved; however the fundamental shortcoming which characterizes them cannot be overcome. They cannot deliver power beyond their ability to store it. It would be impractical to carry sufficient batteries for supplying auxiliary power in warm weather and impossible in cold weather.

Elimination of some or all of these stumbling blocks will enable electrical engineers to exploit further the use of electricity throughout the airplane. One solution lies in the use of one of the three general types of auxiliary power plant which are as follows:

1. Battery chargers.
2. Battery replacers.
3. Continuous duty (providing a primary source of power).

A further breakdown can be made as to the type of electrical output. In this paper it will be done only insofar as the necessity arises.

Battery Chargers

Without altering the accessory system, except for the addition of a little weight, a battery-charging auxiliary power plant can expand its efficiency materially. One main difficulty thus is overcome; batteries can be recharged readily innumerable times independently of the main engines.

The engine itself must be of simple and rugged construction and as small as possible, consistent with the desired charging rate of the unit. For this type of operation a single-cylinder air-cooled two-cycle engine is a good choice since the number of parts inherently is kept to a minimum. The governor need be no more complicated or accurate than the pneumatic-paddle type used on small engines. A flywheel magneto offers the advantage of having a large part of its

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weight performing useful work as flywheel inertia. Battery ignition, if lighter, can be used since the number of batteries with which the unit operates hardly can be discharged to the point where sufficient voltage for ignition is not available. There is no need for a fuel pump if the unit can be located slightly below the normal fuel level. However, too much fuel head may complicate the carburetor float-valve arrangement. The choice of cooling system depends somewhat upon the requirements of the generator.

A unit of this type has been in use for over a decade in the Navy's flying boats. It consists of a small one-cylinder two-cycle engine driving a combination a-c and d-c generator and has provisions for attaching another accessory. Its long record speaks for itself.

Battery Replacer

The great strides made in the development of generators for main engines resulted in a set back for the continuous-duty type of auxiliary power plant which was being developed to overcome, among other things, low generator output. The resulting increase in electrical loads on airplanes made batteries even less adequate as a source of auxiliary power and led to the development of an auxiliary power plant for replacing batteries.

The battery-replacing type, like the battery charger, is best suited to military aircraft and flying boats, as its main purpose is to provide a more adequate source of auxiliary power where ground-type units are not available. Development of its inherent advantages will make it a common sight in postwar airplanes of all types.

Figure 1 indicates an approximate battery-output curve for a given load as compared with the output curve of an auxiliary power plant. Assuming that the efficiency of the two systems is approximately equal (that is converting of British thermal units in gasoline to kilowatts of auxiliary power) an obvious advantage is apparent.

The output of this type of unit is determined by the largest necessary continuous load required. Although it would be desirable to have sufficient output to handle breakaway surges and to operate several accessories simultaneously, the weight would be objectionable. Figure 2 illustrates roughly the demand curve of an electrical accessory as compared with the output curve of a battery-replacing auxiliary power plant of proper size. Note the shaded area indicating the energy to be supplied by the remaining battery

The engine for the battery-replacing auxiliary power plant is larger than for the battery charger and naturally offers a wider choice as to arrangement. The number of cylinders may vary from two

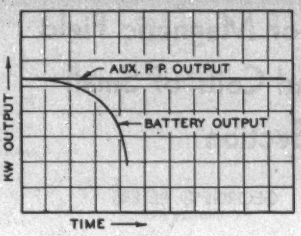

Figure 1. Auxiliary power plant versus batteries

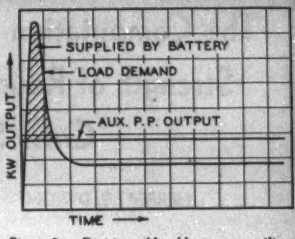

Figure 2. Division of load between auxiliary power plant and small battery

to five and be arranged radially, vee, opposed, in line, or in almost any conceivable manner that results in a compact accessible engine. Either the two- or four-stroke cycle may be used; operating conditions favor the four stroke somewhat. Magneto ignition is desirable and smaller engines of the group may find a weight advantage in a flywheel magneto. The fuel pump should be eliminated, if possible, unless combined with a fuel injector which becomes more practical on larger engines. From the standpoint of first cost and servicing, consideration must be given to the possibility of designing a majority of parts for use in a series of models having varying outputs. This should not be done to the detriment of weight and performance. Controls and other equipment must be determined by the requirements of each installation.

Continuous Duty

The third type of auxiliary power plant, previously mentioned briefly, is one which runs continuously providing a primary source of power. Although certain units of this type have given good service, their development was not advanced sufficiently to compete with improved main-engine-driven generators, and manufacturers turned to the second type mentioned.

Prospects of return of the continuous-duty type are likely when the advantages are considered; some of these are as follows:

1. It rounds out the power system into a complete unit independent of main engines and ground equipment.

2. High-voltage alternators can be used individually or in parallel.

3. Congestion of main-engine accessory sections can be relieved.

Further elaboration on these advantages is unnecessary since they have been discussed many times in various papers. However, one substantial disadvantage does bear mentioning at this time: auxiliary power plants require essentially the same maintenance as main engines do.

Performance records indicate that time between overhauls beyond 1,000 hours is reasonable. This fact coupled with an engine designed for easy maintenance will minimize this objection materially.

The engine for the continuous-duty type of unit generally will be larger than either of the foregoing types, but in many cases it will be identical with the one used in the battery-replacing unit, except for controls and supercharging. For the extreme altitudes at which operation will be required external supercharging has many advantages. Supplementary cooling will be necessary and may be obtained from an air scoop.

As the size of airplanes and, consequently, the demand for auxiliary power increases beyond a certain point, another primary source of auxiliary power may be developed in the form of a steam turbine. Recent trends toward using exhaust gases for deicing as well as for turbosuperchargers might preclude their use as heat for generating steam. This should not hamper the system a great deal since a separately fired boiler would be desirable to provide power independently of main engines.

In order to have auxiliary power plants meet the requirements in the best possible way, close co-operation between manufacturers of airplanes, main engines, auxiliary engines, and accessories (electrical) will be essential.

One of the best ways to save weight on auxiliary engines is to eliminate accessories and structures that are duplicated elsewhere in the airplane. In an effort to relieve the congestion behind main engines some airplanes are equipped with gear boxes. By designing into the gear box an auxiliary engine which would make use of the generator, oil pump, and fuel pump already required, considerable weight could be saved over batteries or conventional auxiliary power-plant installations. The auxiliary engine would drive only the necessary components of the gear box to keep friction at a minimum and would be operated when needed. During flight the auxiliary engine could be kept warm and ready for use by circulating gear-box oil through it.

Continuous-duty auxiliary power plants, like main engines, require supercharging. With a slight increase in the size of the main engine supercharger

The Computation of Magnetic Field Strength of Round Coils of Small Cross Section

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WHEN a solenoid, or cylindrical coil, has no iron core, the magnetic field in the space around it or within it may be computed very precisely. Formulas have been published[1] which take account of the length and thickness of the coil by algebraic terms which have been obtained by an integration over the cross section of the coil. This requires a calculation to be made twice, once for the end of the coil nearer the point for which the magnetic field is being computed, and once for the farther end. When the distance to this point is large compared with the dimensions of the coil section, the final computed result is a small difference of two larger quantities, resulting in a loss of accuracy. In this paper formulas for the magnetic field strength are presented which not only preserve the accuracy of computation, in such cases where they are applicable, but also save a considerable amount of work.

When the length and thickness of the solenoid or coil are so small compared with the radius that they may be neglected, formulas are available which give the field strength directly in terms of elliptic integrals[2] or of a series of zonal harmonics (see equations 12 to 24 of reference 1, and the earlier references given therein). These formulas can be used with actual coils by taking the position and diameter of the coil to be those of the circle at the middle of the coil section.

In this paper, correction formulas are given which can be used along with those of the preceding paragraph, and which will give the effect of the dimensions of the cross section. These formulas are in the form of convergent series, and, as is usual in such cases, their applicability is determined by the rapidity with which

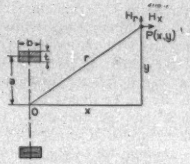

Figure 1. Circular coil

the terms become smaller and smaller, for any given problem. If in any case they are found inapplicable for this reason, recourse may be had to the more general set of formulas indicated by numbers in Figure 5, of reference 1.

A general method by which correction terms for the section of a cylindrical coil may be derived is given in "Electricity and Magnetism" by J. C. Maxwell, volume 2, para. 700. If the coil section, which is a rectangle of length b and radial dimension t, be plotted with the middle point of the section as origin, then the magnetic field due to any small circular wire through the point (u, v) may be called H_{uv}. Expressing this as H_o and a series of its derivatives, and integrating from $-t/2$ to $t/2$ and from $-b/2$ to $b/2$, there results

$$H_{\text{coil}} = H_o + \Delta H_o$$

H_o is the magnetic field strength due to the single turn at the center of the cross section, the entire current of the cross section being taken to be concentrated in this turn. H_o may be computed by any of the formulas for single circular turns described in the preceding paragraphs.

$$\Delta H_o = \frac{1}{1!3!2^2}\left(t^2\frac{\partial^2 H_o}{\partial a^2} + b^2\frac{\partial^2 H_o}{\partial x^2}\right) + \frac{1}{1!5!2^4}\times \left(t^4\frac{\partial^4 H_o}{\partial a^4} + b^4\frac{\partial^4 H_o}{\partial x^4}\right) + \frac{1}{3!3!2^4}t^2b^2\frac{\partial^4 H_o}{\partial a^2 \partial x^2} + \ldots \quad (1)$$

A case in which the method of this paper is very applicable is where the point $P(x, y)$ (see Figure 1), at which the value of the magnetic field strength is desired, is at a large distance from the coil.

A formula for the axial component of the magnetic field for this case is equation 20, reference 1, as follows:

$$H_{xo} = \frac{2\pi NI}{10r}\left[\frac{a^2}{r^2}P_2\left(\frac{x}{r}\right) - \frac{3}{2}\frac{a^4}{r^4}P_4\left(\frac{x}{r}\right) + \frac{3\cdot5}{2\cdot4}\frac{a^6}{r^6}P_6\left(\frac{x}{r}\right) - \frac{3\cdot5\cdot7}{2\cdot4\cdot6}\frac{a^8}{r^8}P_8\left(\frac{x}{r}\right) + \ldots\right] \quad (2)$$

By applying equation 1, there is obtained

$$\Delta H_{xo} = \frac{2\pi NI}{10r}\left[C_{(2)}\frac{a^2}{r^2}P_2\left(\frac{x}{r}\right) - C_{(4)}\frac{3}{2}\frac{a^4}{r^4}P_4\left(\frac{x}{r}\right) + C_{(6)}\frac{3\cdot5}{2\cdot4}\frac{a^6}{r^6}P_6\left(\frac{x}{r}\right) - C_{(8)}\frac{3\cdot5\cdot7}{2\cdot4\cdot6}\frac{a^8}{r^8}P_8\left(\frac{x}{r}\right) + \ldots\right] \quad (3)$$

where

$$C_{(2)} = \frac{t^2}{12a^2}$$

$$C_{(4)} = \left(\frac{t^2}{2a^2} - \frac{b^2}{3a^2} + \frac{t^4}{80a^4} - \frac{t^2b^2}{36a^4}\right)$$

$$C_{(6)} = \left(\frac{5}{4}\frac{t^2}{a^2} - \frac{b^2}{a^2} + \frac{3}{16}\frac{t^4}{a^4} - \frac{t^2b^2}{2a^4} + \frac{b^4}{10a^4} + \ldots\right)$$

$$C_{(8)} = \left(\frac{7}{3}\frac{t^2}{a^2} - \frac{2b^2}{a^2} + \frac{7}{8}\frac{t^4}{a^4} - \frac{5}{2}\frac{t^2b^2}{a^4} + \frac{3}{5}\frac{b^4}{a^4} + \ldots\right)$$

Similarly, the radial component at the point $P(x, y)$ is, by equation 21, reference 1,

$$H_{ro} = \frac{\pi NIy}{10r^2}\left[\frac{a^2}{r^2}P_2'\left(\frac{x}{r}\right) - \frac{3}{4}\frac{a^4}{r^4}P_4'\left(\frac{x}{r}\right) + \frac{3\cdot5}{4\cdot6}\frac{a^6}{r^6}P_6'\left(\frac{x}{r}\right) - \frac{3\cdot5\cdot7}{4\cdot6\cdot8}\frac{a^8}{r^8}P_8'\left(\frac{x}{r}\right) + \ldots\right] \quad (4)$$

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enough air could be supplied for the auxiliary power plant more efficiently than from a separate supercharger built into the auxiliary engine. This has been done with good results.

Another source of "cheap" supercharging may be found in the exhaust from cabin supercharging. The auxiliary power plant could be mounted inside or outside the pressurized cabin. However, mounting it inside the cabin would be better from the standpoint of heat dissipation.

Auxiliary-engine accessories such as magnetos, fuel pumps, and carburetors can stand considerable improvement from the weight standpoint. Such equipment on most auxiliary engines is capable of serving engines many times larger.

Although auxiliary power plants necessarily are operating within the range of diminishing returns from the standpoint of weight and efficiency they reopen the avenues of development to designers of electrical equipment. Co-operation along the lines mentioned can result in better and lighter accessory power systems.

The same coefficients are used for each term as in equation 3; thus, by equation 1,

$$\Delta H_{r_0}=\frac{\pi NIy}{10r^2}\left[C_{(3)}\frac{a^3}{r^3}P_2'\left(\frac{x}{r}\right)-C_{(4)}\frac{3}{4}\frac{a^4}{r^4}P_4'\left(\frac{x}{r}\right)+C_{(6)}\frac{3\cdot5}{4\cdot6}\frac{a^6}{r^6}P_6'\left(\frac{x}{r}\right)-C_{(8)}\frac{3\cdot5\cdot7}{4\cdot6\cdot8}\frac{a^8}{r^8}P_8'\left(\frac{x}{r}\right)+\dots\right] \quad (5)$$

In the above formulas, the magnetic field is given at the point (x, y), the center of the round coil being the origin of co-ordinates and the axis of the coil being the axis of x. See Figure 1. The quantity $r^2=x^2+y^2$. The coil has a mean radius of a centimeters. Its cross section is rectangular, the radial thickness being t and the axial length, b. It is evident from the form of equations 3 and 5 that t and b should be small compared with the radius a for these formulas to be applicable. Dimensions are in centimeters. The dots represent multiplication.

$P_n(\mu)$ is a surface zonal harmonic. It may be computed by standard formulas[3] or the required values may be taken from tables.[4] $P_n'(\mu)=\frac{d}{d\mu}P_n(\mu)$.

Since these formulas are to be used when there is no iron or magnetic material near the coil, the flux density at the point $P(x, y)$, in lines per square centimeter, is numerically equal to the value of H given by the formulas.

Example 1. For a numerical example, take $a=10$ centimeters, $t=0$, $b=5$ centimeters, $x=24$ centimeters, and $y=32$ centimeters. See Figure 1. Then:

$r^2=1{,}600$, $r=40$, and $x/r=0.6$

By equation 2,

$$H_{z_0}=\frac{2\pi NI}{10^4a}\times\frac{10}{40}(2.500+2.391+0.079-0.007\dots)=\frac{2\pi NI}{10^4a}\times1.241$$

$$\Delta H_{z_0}=\frac{2\pi NI}{10^4a}\times\frac{10}{40}\left(-2.391\times\frac{1}{12}-0.079\times\frac{39}{160}+0.007\times\frac{37}{80}\dots\right)=\frac{-2\pi NI}{10^4a}\times0.054$$

$$H_z=H_{z_0}+\Delta H_{z_0}=\frac{2\pi NI}{10^4a}\times1.187$$

An alternative way of computing this result is by two applications of equation 39, reference 1. First, with $t=0$, by equation 39,

$$H_{z_1}=H_{z_0}-\frac{\pi nI}{10}\left[\frac{a^2}{r_1^2}P_1\left(\frac{x_1}{r_1}\right)-\frac{3}{4}\frac{a^4}{r_1^4}P_3\left(\frac{x_1}{r_1}\right)+\frac{3\cdot5}{4\cdot6}\frac{a^6}{r_1^6}P_5\left(\frac{x_1}{r_1}\right)-\frac{3\cdot5\cdot7}{4\cdot6\cdot8}\frac{a^8}{r_1^8}P_7\left(\frac{x_1}{r_1}\right)+\dots\right]$$

where

$$H_{z_0}=\frac{2\pi nI}{10}$$

$$n=\frac{N}{b}=\text{turns per centimeter}$$

$$r_1^2=x_1^2+y^2$$

$$x_1=x-\frac{b}{2}=24-2.5=21.5 \text{ centimeters}$$

$$H_{z_1}=\frac{\pi NI}{10a}\times\frac{a}{b}[2-0.037523+0.001368+0.0000090+0.0000034+0.0000001\dots]$$

$$=\frac{\pi NI}{10a}\times\frac{10}{5}\times1.961121$$

For

$$x_2=x+\frac{b}{2}=24+2.5=26.5,$$

$$H_{z_2}=\frac{\pi NI}{10a}\times\frac{10}{5}\times1.962307$$

$$H_z=H_{z_2}-H_{z_1}=\frac{2\pi NI}{10a}(1.962307-1.961121)=\frac{2\pi NI}{10^4a}\times1.186$$

This agrees very well with the result by means of ΔH_0. The method by equation 39 takes about twice as long as equations 2 and 3, for this example. It has the advantage that further terms can be computed indefinitely if desired.

For the same shape of coil as has been taken up, namely, with t and b small compared with the radius a, the magnetic field strength near the center of the coil can be computed by means of equation 1, by applying it to equations 17 and 19 of reference 1.

By equation 17,

$$H_{z_0}=\frac{2\pi NI}{10a}\left[1-\frac{3}{2}\frac{r^2}{a^2}P_2\left(\frac{x}{r}\right)+\frac{3\cdot5}{2\cdot4}\frac{r^4}{a^4}P_4\left(\frac{x}{r}\right)-\frac{3\cdot5\cdot7}{2\cdot4\cdot6}\frac{r^6}{a^6}P_6\left(\frac{x}{r}\right)+\dots\right] \quad (6)$$

By equation 1,

$$\Delta H_{z_0}=\frac{2\pi NI}{10a}\left[D_{(0)}-D_{(2)}\frac{3}{2}\frac{r^2}{a^2}P_2\left(\frac{x}{r}\right)+D_{(4)}\frac{3\cdot5}{2\cdot4}\frac{r^4}{a^4}P_4\left(\frac{x}{r}\right)-D_{(6)}\frac{3\cdot5\cdot7}{2\cdot4\cdot6}\frac{r^6}{a^6}\times P_6\left(\frac{x}{r}\right)+\dots\right] \quad (7)$$

where

$$D_{(0)}=\left(\frac{t^2}{12a^2}-\frac{b^2}{8a^2}+\frac{t^4}{80a^4}-\frac{t^2b^2}{16a^4}+\frac{3}{128}\frac{b^4}{a^4}\dots\right)$$

$$D_{(2)}=\left(\frac{t^2}{2a^2}-\frac{5}{8}\frac{b^2}{a^2}+\frac{3}{16}\frac{t^4}{a^4}-\frac{25}{32}\frac{t^2b^2}{a^4}+\frac{35}{128}\frac{b^4}{a^4}\dots\right)$$

$$D_{(4)}=\left(\frac{5}{4}\frac{t^2}{a^2}-\frac{35}{24}\frac{b^2}{a^2}+\frac{7}{8}\frac{t^4}{a^4}-\frac{245}{72}\frac{t^2b^2}{a^4}+\frac{147}{128}\frac{b^4}{a^4}\dots\right)$$

$$D_{(6)}=\left(\frac{7}{3}\frac{t^2}{a^2}-\frac{21}{8}\frac{b^2}{a^2}+\frac{21}{8}\frac{t^4}{a^4}-\frac{315}{32}\frac{t^2b^2}{a^4}+\frac{2{,}079}{640}\frac{b^4}{a^4}\dots\right)$$

For the radial component of the field near the coil center, by equation 19, reference 1,

$$H_{r_0}=\frac{\pi NIyr}{10a^3}\left[P_2'\left(\frac{x}{r}\right)-\frac{3}{4}\frac{r^2}{a^2}P_4'\left(\frac{x}{r}\right)+\frac{3\cdot5}{4\cdot6}\frac{r^4}{a^4}P_6'\left(\frac{x}{r}\right)-\dots\right] \quad (8)$$

and, by equation 1,

$$\Delta H_{r_0}=\frac{\pi NIyr}{10a^3}\left[D_{(2)}P_2'\left(\frac{x}{r}\right)-D_{(4)}\frac{3}{4}\frac{r^2}{a^2}P_4'\left(\frac{x}{r}\right)+D_{(6)}\frac{3\cdot5}{4\cdot6}\frac{r^4}{a^4}\times P_6'\left(\frac{x}{r}\right)-\dots\right] \quad (9)$$

where $r^2=x^2+y^2$ and where the coefficients $D_{(2)}$, $D_{(4)}$, and $D_{(6)}$ are given after equation 7.

The results described in this paper were derived in connection with a thesis at Massachusetts Institute of Technology.

Formulas for the first few surface zonal harmonics are:

$P_1(\mu)=\mu \qquad P_2(\mu)=\frac{1}{2}(3\mu^2-1)$

$P_3(\mu)=\frac{1}{2}(5\mu^3-3\mu)$

$$P_4(\mu)=\frac{1}{2\cdot4}(5\cdot7\mu^4-2\,3\cdot5\mu^2+1.3)$$

$$P_5(\mu)=\frac{1}{2\cdot4}(7\cdot9\mu^5-2\cdot5\cdot7\mu^3+3\cdot5\mu)$$

$$P_6(\mu)=\frac{1}{2\cdot4\cdot6}(7\cdot9\cdot11\mu^6-3\cdot5\cdot7\cdot9\mu^4+3\cdot3\cdot5\cdot7\mu^2-1\cdot3\cdot5)$$

$$P_7(\mu)=\frac{1}{2\cdot4\cdot6\cdot8}(9\cdot11\cdot13\cdot15\mu^7-4\cdot7\cdot9\cdot11\cdot13\mu^5+6\cdot5\cdot7\cdot9\cdot11\mu^4-4\cdot3\cdot5\cdot7\cdot9\mu^3+1\cdot3\cdot5\cdot7)$$

$P_1'(\mu)=1 \qquad P_2'(\mu)=3\mu$

$P_3'(\mu)=\frac{1}{2}(3\cdot5\mu^2-1\cdot3)$

$P_4'(\mu)=\frac{1}{2}(5\cdot7\mu^3-3\cdot5\mu)$

and so on, by simple differentiation of the formulas given above.

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Aircraft-Engine Torque Instruments

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Synopsis: Flight-operations experience has shown that significant improvements in fuel economy may be obtained through the use of aircraft-engine torque instruments as regular flight instruments. This paper describes the better-known types of torque instruments and introduces a new type that has recently come through its development stage.

THE performance of airplane engines in flight is evaluated ordinarily by means of engine speed, manifold pressures, air temperature, airplane speed, and flight altitude in terms based upon factory-calibrated engines. Corrections for fuel variations, atmospheric humidity, and actual engine condition are usually indeterminate and cannot be applied, so that substantial variations from the "chart" engine output frequently are encountered. Torque measuring instruments have been used when available for test flying of new aircraft designs and to a limited extent as regular flight instruments to reduce fuel consumption and extend the useful radius of flight operations. The value of a torque instrument on the propeller shaft of an airplane engine lies in a balance between the advantage of knowing true engine-power delivery and the disadvantage of additional weight, service difficulties, and increased equipment cost. For very long-range operations of large military aircraft, engine torque instruments or some accurate type of power-measuring devices are a necessity and a military requirement. As ranges are shortened and as airplane size decreases, excessive torque-instrument weight and cost increases can quickly outweigh their advantages.

General Types of Torque Instruments

There are two general types of torque instruments which have been applied to aircraft engines to determine engine output; these are the hydraulic and the electrical types. The hydraulic torque instrument[1,2] is the better known of the two and has been in use for a number of years; it usually measures the torque reaction on a stationary member of the propeller-shaft reduction-gear train by means of an hydraulic piston and a pressure-regulated oil supply. The oil pressure is controlled by means of slight piston movements to balance exactly the torque reaction of the selected gear, usually the stationary sun gear of a planetary gear set, Figure 1, and the oil pressure which is proportional to the torque is measured by a conventional pressure gauge. When double-reduction gears are required, or when operation at an extremely low temperature is necessary, and when excessive torsional vibrations are present, the hydraulic system becomes difficult to handle. Electric torque instruments fall into three general classifications, the strain-resistive, strain-capacitive, and strain-magnetic.

Electrical-Resistance Strain Gauges

The strain-resistive type may measure either the twist in the propeller shaft by means of strain-sensitive resistance elements mounted directly on the shaft, or it may measure the deflections of a stationary reaction member, somewhat similar to the conventional hydraulic torque instrument in application except that the actual deflection of a spring is measured rather than the balancing oil pressure. If the strain-sensitive resistance elements are attached to a stationary reaction member, direct electric connections can be made between the resistance units and the indicating instrument; but if the resistance units are mounted on a rotating shaft so as to be sensitive to the actual twist in a specified gauge length of shaft, electric connections usually must be made through slip rings on the shaft with brushes riding on the slip rings, Figure 2. Attempts have been made to use carbon-pile resistance elements in such torque instrument or strain-gauge applications because of the high energy levels which can be tolerated in carbon piles. This should make possible direct indication of torque on conventional ammeters or voltmeters without using amplifiers; however, the strain-resistance characteristics of carbon piles have not been sufficiently stable and subject to manufacturing control within required accuracy limits to permit their use. Wire-resistance strain gauges[3] have the required accuracy, but the resistance changes for strains corresponding to maximum allowable stresses in both the engine parts and the wire-resistance elements seldom exceed one per cent of the initial resistance. Therefore, use of a sensitive potentiometer and balancing bridge is required with wire-resistance strain gauges, or high-gain electric amplifiers must be used with direct-indicating instruments. The ease of application of the small resistance-wire strain gauge and its general reliability makes it quite valuable for laboratory work, but its low sensitivity appears to rule it out as an aircraft flight instrument. A further disadvantage is the relatively large temperature coefficient of resistance of most of the wire-resistance strain gauges; normal temperature excursions in aircraft engines result in temperature-resistance changes of greater magnitude than the strain-resistance changes under measurement; these temperature effects can be eliminated, however, by careful adjustment of compensators.

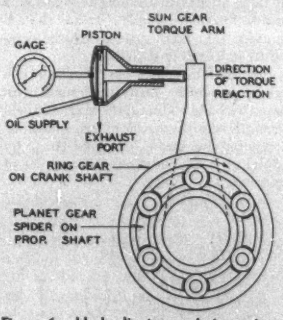

Figure 1. Hydraulic torque instrument applied to sun gear of planetary transmission

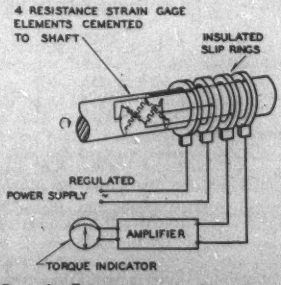

Figure 2. Torque instrument using resistance-wire strain gauges attached to shaft

Electrical-Capacitance Strain Gauges

Strain-capacitive elements are used in much the same manner as strain-resistive elements, and may be mounted either on rotating shafts with slip-ring connections or on torque-responsive stationary members of the engine. Here an air-dielectric capacitor is formed of two groups of plates or conducting surfaces insulated from each other and so positioned that, when the assembly is subjected to strain, either dielectric spacing between plates of opposite polarity changes or opposed plate areas

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alter in proportion to the strain, with a resultant change in the capacitance of the capacitor. The per cent change in capacitance which can be obtained for permissible strains in engine parts can be large, and for that reason much effort has been expended in attempts to utilize strain-capacitive elements in strain gauges and torque instruments. However, space and weight limitations usually restrict the capacitance of the strain-sensitive element to a few micromicrofarads; and therefore, even with a-c power supplies of several hundred kilocycles frequency, energy levels in the sensitive circuit elements are so low as to require amplifiers ahead of the torque indicating instrument, with the usually attendant difficulties of maintaining calibration. Capacitance-sensitive strain elements must also be hermetically sealed to exclude oil, moisture, and dirt; and the uncertain stray capacitances of electric connections and mechanical supports are also major difficulties.

Electromagnetic Strain Gauges

Strain-magnetic elements lend themselves to the measurement of small displacements much more readily than do any of the aforementioned strain-sensitive devices when it is desirable to connect direct-indicating instruments to the strain-sensitive circuit without interposing amplifiers. The conventional magnetic strain gauges operates at sufficiently high energy levels that its output can be utilized to drive an indicating instrument directly; and in such manner it is commonly used as the sensitive element in many precision gauges or comparators as well as for aircraft-engine testing.[4]

It is usually small and operates on conventional a-c supply circuits, 60 cycles in the case of ground equipment and 400 cycles for air-borne equipment, and can take any one of several different forms; the one in Figure 3 with its connection diagram shown in Figure 4 is simple and commonly used. It consists of two iron-core inductance coils with variable-length air gaps in their magnetic paths; moving the armature A of Figure 4 to the left will decrease the air gap of coil Z_1, increasing its inductance, and at the same time will increase the air gap of coil Z_2 with a corresponding decrease of its inductance. Since Z_1 and Z_2 are both elements of a four-arm bridge, the output of the bridge indicated by the instrument M will be almost exactly proportional to the physical displacement of the armature A from its center position, within the useful limits of the strain gauge. The other two bridge arms, Z_3 and Z_4, are usually made part of a center-tapped autotransformer, which decreases the bridge impedance and thus increases the maximum signal energy available.

Magnetic strain gauges can be mounted in the take-off head of the conventional hydraulic torque instrument, replacing the hydraulic piston and pressure gauge. When this is done, a spring element, usually a short section of steel tubing, resists the reaction of the sun-gear torque arm and the strain gauge measures the deflections of the steel tube, Figure 5. They also have been mounted directly upon the propeller shaft of an engine or reduction-gear assembly, Figure 6, with electric connections made through slip rings on the shaft.

The Magnetic-Coupled Torquemeter

For shaft mounting, the slip-ring design is likely to be difficult from the standpoints of service trouble and contact resistance. On the other hand, there are numerous aircraft-engine applications for torque instruments where it is desirable if not imperative to measure the twist in a shaft when the engine output is to be known with any degree of accuracy. The Magnetic-Coupled Torquemeter therefore was designed to eliminate slip rings and still retain a shaft-mounted strain gauge. A schematic illustration appears in Figure 7, and a picture of a typical assembly is reproduced in Figure 8. If we refer to Figure 7, the shaft is provided with three flanges on which are mounted three toothed rings of magnetic material, but separated from contact with the steel shaft by means of nonmagnetic spacers made of a metal such as bronze or brass. Overlapping teeth or projections from each of the three magnetic rings form two sets of air gaps, one set between outer ring 1 and the middle ring A, and one set between outer ring 2 and the middle ring A. When the shaft is loaded or twisted in a clockwise direction, the air gaps between teeth on rings 1 and A are shortened and the air gaps between teeth on rings 2 and A are lengthened; this is in effect the same as moving the armature A of Figure 4 to the left.

Magnetic flux flows across the two sets

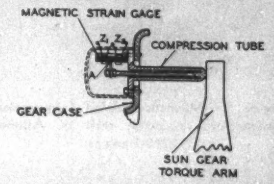

Figure 5. Magnetic strain gauge applied to sun gear of planetary transmission

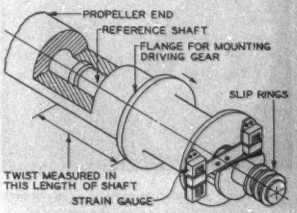

Figure 6. Magnetic strain gauges measuring the twist of a propeller shaft

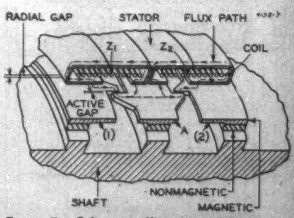

Figure 7. Schematic illustration of Magnetic-Coupled Torquemeter

Figure 3. Magnetic strain gauge

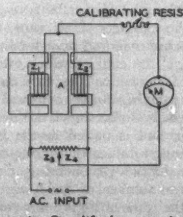

Figure 4. Simplified magnetic-strain-gauge circuit

Figure 8. Small Magnetic-Coupled Torquemeter for test-floor use

Figure 9. Magnetic-Coupled Torquemeter designed for propeller shaft of Allison V-1710-E engine

Figure 10. Magnetic-Coupled Torquemeter rotor with four tooth gaps per side

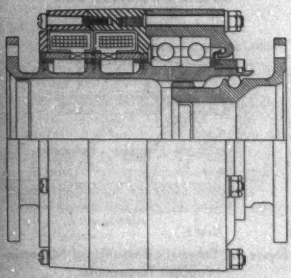

Figure 11. Magnetic-Coupled Torquemeter designed for the engine extension shaft of an Allison engine

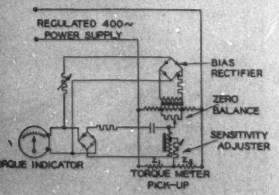

Figure 12. Electric circuit for a magnetic strain gauge or Magnetic-Coupled Torquemeter using a regulated power supply

of air gaps, induced by the two stationary coils Z_1 and Z_3, also corresponding to Z_1 and Z_2 of Figure 4. Coils Z_1 and Z_3 are shown completely encircling the shaft assembly and the magnetic return paths are through their encasing shells of magnetic material and across the radial air gaps between the stationary-coil assembly and the rotating-shaft assembly. These air gaps have relatively large effective areas and short lengths so that their magnetic permeances are quite large compared with the permeances of the active air gaps between the toothed rings; consequently, the insertion of the radial air gaps in the magnetic circuit has but small effect upon the characteristics of the strain gauge. Normal eccentric movements of the rotating shaft in its bearings relative to the stator cause second-order changes in permeance of the radial air gaps and finally result in only third-order changes in torque-instrument calibration.

When strain-gauge elements are mounted on a rotating shaft, precautions must be taken to avoid errors due to bending moments and compression or tension loads on the shaft so that only pure torque is measured. This requires that a balanced magnetic circuit be used with both Z_1 and Z_2 responsive to shaft torque loads, and it also requires that the sensitive air gaps be distributed uniformly around the circumference of the shaft. Slip-ring installations of two conventional magnetic strain gauges diametrically opposite each other on a shaft and with their coil circuits either connected in series or in parallel have shown a satisfactory lack of response to bending loads on the shaft where moderate loads are imposed. Some aircraft-engine propeller shafts are subjected to bending moments from propeller gyroscopic couples in spins that may result in maximum fiber stresses of the order of 100,000 pounds per square inch where normal stress in torsion is of the order of 8,000 to 16,000 pounds per square inch.

Well-distributed sets of sensitive air gaps are desirable in such circumstances, and Figure 9 shows a rotor for a magnetic-coupled torque instrument with a large number of small individual air gaps in each set around the shaft. This particular shaft element is intended to be mounted between two existing flanges on an engine propeller shaft, and therefore, in order to divide circumferential strain due to twist in the shaft length between flanges equally between the two sets of air gaps, three rotor rings are mounted on a torsionally flexible cage, the ends of which are permanently fastened to the two flanges. The stator carrying the two coils and their magnetic shells is also shown in the same illustration, and is bolted to the inner-thrust-bearing retainer ring inside of the propeller reduction-gear housing.

The large number of small air gaps shown in the rotor of Figure 9 is very effective in averaging out bending and thrust loads on the propeller shaft, but does lead to excessive magnetic leakage around the teeth and also to increased manufacturing difficulties since normal air-gap spacing is of the order of 0.004 to 0.010 inch, depending upon shaft stiffness characteristics. Another rotor for the same application is shown in Figure 10 in which only four air gaps each of relatively large area are used per sensitive gap set; there is a considerable increase in apparent sensitivity of this torque instrument over the one shown in Figure 9, due to the better magnetic design and the large reduction in leakage flux around the rotor. Flux leakage at 400 cycles per second to the steel shaft is effectively reduced to a negligible quantity if the nonmagnetic spacer rings between the toothed rings and the shaft are made of high-conductivity materials such as brass, bronze, or copper.

Figure 11 shows another magnetic-coupled torque instrument intended for use on the extension shaft between the engine and a separate propeller reduction-gear box. The three toothed magnetic rings are mounted on three shaft flanges instead of on a flexible cage, and the short shaft section carrying the rings is inserted in the extension-shaft drive with flanged or splined couplings. A better mechanical job is obtained when it is possible to mount the toothed rings directly upon individual flanges integral with the shaft rather than upon the surface of a flexible cage or sleeve.

Temperature Effects in Magnetic Strain Gauges

The effects of ambient-temperature changes upon magnetic strain gauges can be divided into those originating in the instrument circuit and those originating in the shaft pickup unit. Temperature effects in the instrument circuit are readily corrected by conventional means and attention to good design practice. The temperature effects in the shaft element are more difficult to handle ordinarily, particularly since temperatures may range from −50 degrees centigrade to hot engine oil temperatures. The changes in modulus of elasticity of the shaft material are usually small over the normal temperature ranges, but serious unbalances of the impedance bridge with large shifts in the zero adjustment of the torque instrument may result from large ambient-temperature changes around the shaft pickup unit; this may be particularly noticeable when large temperature differentials appear from one end of the shaft unit to the other. These calibration changes can be held to small limits if sufficient care is used in design to prevent large hysteresis and eddy-current losses in the magnetic parts of the shaft unit. High power factors in the impedance coils of the strain-gauge bridge usually are the result of abnormal magnetic losses due to saturation effects in parts of the circuit;

and such losses are usually highly temperature-sensitive, so that torque-instrument accuracy suffers from temperature changes. By exercising care in design and application, these temperature effects can be held within acceptable limits; one of the early Magnetic-Coupled Torquemeters that showed excessive temperature sensitivity was corrected by adding a small resistor with a high temperature coefficient of resistivity in series in one of the impedance coil arms of the bridge. A nickel-wire resistor was used and fastened to the shaft pickup stator housing.

Magnetic-Strain-Gauge Instrument Circuits

A number of precautions must be observed in applying magnetic strain gauges or Magnetic-Coupled Torquemeters to aircraft instrumentation problems. The a-c power supplies ordinarily available on airplanes may be subject to rather wide variations in voltage and frequency; and, while close frequency regulation is not essential, the calibration of the torque instruments is proportional to the supply voltage when a simple circuit such as shown in Figure 4 is used. Therefore a voltage-regulated power supply is essential to accurate calibration under these circumstances. Since the electrical load is small and fixed, the voltage-regulator problem is not particularly difficult. The power requirements of a magnetic strain gauge at 400 cycles is about five voltamperes. The Magnetic-Coupled Torquemeter, due to greater iron loss and flux leakage requires 30 to 50 volt-amperes. Ordinary frequency variations are compensated for, when compensation is required, by the use of a small capacitor in the instrument circuit. On airplanes where the only available electric power is direct current, it is possible to use a small inverter to obtain the necessary 400 cycle power. Various regulators, such as the carbon-pile, saturated-reactor, and centrifugal speed-governing type are available. By designing a unit specially for the job, it is possible to reduce the weight of the inverter, complete with regulator, to about two pounds per torque instrument on a two-engine airplane.

The indicating instrument is usually a rectifier-type milliammeter, and the complete bridge output circuit must include the proper external resistances to insure that the instrument circuit will provide accurate voltage measurements of the strain-gauge bridge output over wide ranges of ambient temperature, input voltage, and frequency. Such a circuit is shown in Figure 12, which is Figure 4 with the added refinements of a voltage regulator, frequency-compensating capacitor, sensitivity-adjusting rheostat, zero-balance potentiometer, and a small bias rectifier. The bias rectifier is added, because a true null balance of the bridge is never obtainable because of the presence of phase unbalance and harmonics in the supply voltage. Therefore, without a biasing rectifier or an off-scale zero spring adjustment, the indicator pointer could never be brought to zero.

The use of a d-c ratio instrument instead of a conventional milliammeter eliminates the necessity for the voltage regulator, and since frequency variations are relatively unimportant in magnetic-strain-gauge instrument errors, its use has many attractive features. A d-c ratio instrument consists of a permanent-magnet instrument movement with two coils set at a wide angle to each other on the shaft of the moving element which carries the pointer. Connections are made to the moving coils through soft gold conducting spirals instead of the conventional springs, and the resultant spring restraint is negligible under normal conditions. When each coil is made to carry current, the position which the pointer will assume is determined by the resultant magnetic field of the two coils, and the instrument scale is marked as the ratio of current flowing in the "forward" coil to that flowing in the "reverse" coil. The torque-instrument application of a d-c ratio instrument is shown in Figure 13, and it should be noted that the coils are energized through instrument-type rectifiers and also that a biasing voltage is required for the forward coil for zero-adjustment purposes. Unfortunately, the scale length of present d-c ratio instruments is limited to that of a 90 degree instrument movement, and the scale is nonlinear. A comparison of the short-scale ratio instrument with a 270-degree-scale-movement aircraft-type milliammeter such as is used in the circuit of Figure 12 is shown in Figure 14.

A greatly simplified torque instrument utilizing the magnetic strain gauge working directly into an a-c ratio instrument is shown in the connection diagram of Figure 15, in which voltage regulators, rectifiers, and all biasing circuits are eliminated. The stationary coil of the instrument is energized directly from the power-supply source, and the moving coil is connected to the bridge output. Current is conducted to the moving coil through soft gold spirals with a minimum of spring restraint, and the moving element comes to rest when the inphase component of the voltage induced in the coil is equal to and opposes the bridge output voltage. Since the power factor of the stationary coil is usually quite low, the out-of-phase voltages induced in the moving coil are small and have a negligible effect upon accuracy. Physically the a-c ratio-instrument movement resembles the conventional frequency-instrument movement. Close coupling between the moving coil and the stationary coil is desirable in order to reduce power requirements, and a laminated silicon steel or Hypernik magnetic structure is used. Long-scale or 270-degree a-c instrument movements have not yet been developed for aircraft use, and the a-c ratio-instrument airplane-engine torque instruments probably will have to wait until such movements are available in production. Figure 16 shows an experimental long-scale a-c ratio-instrument movement for aircraft use compared with a modified wattmeter move-

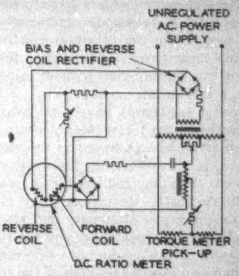

Figure 13. Electric circuit for a magnetic strain gauge or Magnetic-Coupled Torquemeter using an unregulated power supply and a d-c ratio instrument

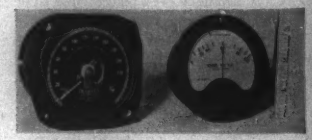

Figure 14. Aircraft-type d-c milliammeter (left) and d-c ratio instrument (right)

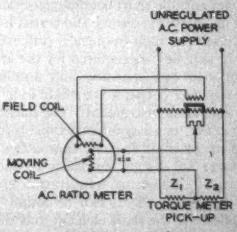

Figure 15. Electric circuit for a magnetic strain gauge using an a-c ratio instrument

Figure 16. A-c ratio instruments

Experimental movement at left, modified wattmeter at right

ment originally designed for marine use and therefore somewhat large and heavy for aircraft applications; both instrument movements operate successfully as a-c ratio instruments.

Other Shaft-Mounted Types Without Slip Rings

Several experimenters have made attempts to utilize various coupling schemes to permit the use of strain-resistive or strain-capacitive gauges mounted directly upon the rotating shaft without using slip rings or electric connections. Strain-sensitive capacitors have been mounted directly on the torque loaded shaft with their terminals connected to the secondary coils of transformers, these coils completely encircling the shaft and rotating with the shaft; the primary coils of the transformers are stationary and also encircle the shaft assemblies and the rotating coils. Mutual inductance between the primary and secondary coils of the rotating transformer thus formed constitutes the link between the stationary instrument circuit elements and the strain-sensitive capacitor on the loaded shaft.

Coils also have been placed close to or encircling shafts to cause magnetic flux to flow in the surface of the shaft itself or through special surface coatings on the shaft, so that, when the shaft is twisted under torque loads and the magnetic permeability and electrical resistivity of the shaft change, such changes are reflected as changes in impedance of the flux-inducing coil or coils.[5] This magnetic skin-effect method of torque measurement is sensitive to temperature, shaft bending, mechanical and magnetic hysteresis, and thrust loads.

Relatively high-frequency (kilocycles) power supplies are required for the aforementioned two schemes, and amplifiers are required between the shaft unit and the indicating instrument. The magnetic skin-effect or magnetostriction torque-instrument shaft element approaches the ultimate in design simplicity; and if means of eliminating temperature errors and hysteresis effects can be found, the simplicity of the shaft element may offset the disadvantages and difficulties of high-frequency power supplies and amplifiers.

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High-Voltage Compressed-Gas Power Transformers

HENRY M. HOBART
FELLOW AIEE

IN a previous article,[1] the author pointed out the many advantages of high-voltage power transmission in compressed gas. Compressed CO_2 at the moderate pressure of 40 atmospheres (absolute) has a dielectric strength about 20 times as high as that of air at normal atmospheric pressure, and compressed SO_2 at 40 atmospheres about 30 times as high, so that the line conductors need be separated by only a few inches instead of the customary many feet and may, therefore, be enclosed in a reasonably small pipe line. This system offers opportunities for many important cumulative economies in the terminal equipment also, and this paper is devoted to their discussion. It is shown that the use of compressed gas, instead of oil, as the insulating and cooling fluid makes possible power transformers that are only about one fourth as large as the present ones for the same duty, are for all intents and purposes nonaging, and are highly resistant to damage from internal arc-overs, besides many other advantages.

While such transformers have not as yet been built, and further laboratory research is desirable on certain phases of the system, yet, based on the great economies shown by several exploratory designs listed in Table II, the author expects that the system will be adopted in the near future to transmit large amounts of power over great distances by transmission lines of very much higher voltages than heretofore and at frequencies as high as 600–1,200 cycles per second.

Important Facts Underlying the System

The more important facts from which the various advantages of the proposed transformer system arise are as follows:

1. The dielectric strength of some compressed gases is greater than that of oil.

2. Gases are not subject to cumulative breakdown to which solid insulation—the backbone of the present-day high-voltage transformers—is subject.

3. Gases have no dielectric loss and can, therefore, be operated at 600–1,000 cycles per second without any harm, making possible corresponding reductions in the sizes of the cores and also of the coils.

4. Unlike oil and the conventional solid insulations used in transformers, gases do not age and are not injured in any way by moderately high temperatures, and therefore the cores of compressed-gas transformers can be operated a couple of hundred degrees centigrade hotter than the windings and the windings a hundred degrees hotter than now to transform much larger kilovolt-amperes per pound than heretofore.

5. For heat transfer, compressed gases are many times more efficient than atmospheric air used in the conventional shell-type air-blast transformers.

These and additional facts and considerations are discussed below in greater detail.

Compressed Gases Versus Oil

Table I shows the leading data on the 60-cycle dielectric strength of several gases at various pressures and that of oil. It will be seen in the table that CO_2 at 40 atmospheres absolute has a 60-cycle strength of 1,650 volts per mil as against 750 volts per mil for oil—a ratio of 2 to 1 in favor of the compressed gas. For transient voltages of steep rise and short duration, such as the 1.5x40 standard impulse wave of the Institute, oil is credited with a strength of twice its 60-cycle value, whereas the strength of the gases is *assumed* to be unchanged. Compressed SO_2 at 40 atmospheres (2,400 volts per mil) is approximately 50 per cent higher than that of either nitrogen or CO_2. No data are now available on the impulse-strength ratios of compressed gases circulated at a high velocity. These may be higher than unity. Laboratory investigation of them, in both uniform and nonuniform fields, is very desirable.

Cumulative Failure of Solid Insulation Under Impulse Voltages

As impulse voltages are of rare occurrence and of very short duration, if a gas does not break down under the sudden stress, it probably will recover from the

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The author is indebted to Glenn B. Warren for suggesting the investigation of underground high-voltage transmission in compressed-gas-filled welded steel pipes, to H. H. Skilling for encouragement derived from his article (reference 3), to the many engineers and scientists mentioned in reference 1, and to the author's own associates.

This paper is speculative and looks toward the future; consequently, it contains many statements of opinion for which there are no supporting data or facts.

shock with its strength unimpaired. But with solid insulations a small permanent harm may be done without apparent failure, and this process will be cumulative. The overvoltage failure of a conventional oil-and-solid-insulated transformer will not take place necessarily at the first heavy surge occasioned by lightning, but after a number of such surges have produced minute but progressive and cumulative impairments. Then, a less severe surge may cause an outage.

Aging of Solid Insulation

It is well-known that the customary fibrous insulations used in oil-filled transformers age physically and become brittle at a rate twice as fast for every eight-degree-centigrade increase in temperature. Every substantial overload thus represents a substantial shortening of the useful life of the transformer. Such an effect does not exist in compressed-gas transformers, and therefore short-time overloads may be handled without any residual harm. Such transformers will be practically nonaging.

Problem of Nonuniform Fields in Gases and Solid Insulations

Uniform distribution of voltage stresses is, of course, desirable no matter what the insulation may be, but in transformers the compressed gases enjoy a particular advantage over solid insulations. In solid insulations overstress implies cumulative damage, and, no matter how small the damage may be per day, cumulation of such damage implies eventual failure. For this reason, in conventional apparatus, the bulk of the solid insulation is operated at a very low and uneconomical stress. A good example of this is the slot-lining insulations in generators and motors. The slot lining of a high-voltage stator winding may prove in the laboratory a strength of several thousand volts per mil in a uniform field and yet, based on experience, be operated at only 30–60 volts per mil on the average.

Because of the greater electronic mobilities in gases, it is wise to proceed at first with generous margins of safety in compressed-gas apparatus, until a sufficient amount of service experience is gained, but such margins of safety are more economically practicable with compressed gases than with oil and solid insulation.

Value of High Frequencies

One of the major economy factors in this system is the use of 600–1,200-cycle frequencies made possible by the replacement of oil and solid insulation by compressed gas. If compressed gas is used in combination with these higher frequencies, sizes drop to about a fourth of their present values.

The voltage produced by a given flux varies directly with the frequency. At tenfold frequency the voltage, and hence the kilovolt-amperes, is ten times as large for the same flux, or the flux required for the same kilovolt-amperes is only one tenth as large. Since, however, at constant flux density, core loss increases with frequency, the same high flux densities may not be used at tenfold frequency as at normal, and the full tenfold benefit may not be secured; yet, by virtue of the permissible high core temperatures and by the use of seven-mil sheet steel it is possible to use sufficiently high flux densities to afford the great economies indicated.

Table I. Dielectric Strength of Four Gases and Commercial Transformer Oil

Tested at 60 Cycles Between Two Spherical Electrodes of 2,500-Mils Diameter With a 100-Mil Gap

Gas Pressure in Atmospheres Absolute	Volts Per Mil (Crest)				
	Air	Nitrogen	CO_2	SO_2	Oil
1	85	95	75	200	750
20	1,300	1,000	1,000	2,000	
40	1,850	1,450	1,650	2,400	
60	2,100	1,550	2,250		

Departure from 60 cycles at this late date may appear to some as impractical, but the best economic course is to utilize 600 cycles (or more) for the major high-voltage transmission system and network of any single enormous territory, and employ frequency changers or rectifiers where the service demands a different frequency or direct current.

These higher frequencies reduce the size not only of the big terminal equipments but also of all power transformers used in the industry. Rectifier installations for electrometallurgical and electrochemical processes, as for the production of aluminum and magnesium, include already several millions of kilovolt-amperes in step-down power transformers. Rectifier applications (all requiring special step-down transformers) for railways, steel mills, mines, and shipyards are rapidly growing. An increase of 10 to 1 in frequency, with compressed-gas insulation, will reduce the size and cost of these transformers to about one seventh.

These higher frequencies are particularly advantageous in welding as to speed, quality, safety, and various other cumulative economies. The a-c arc is more stable and produces a better weld at the higher frequencies, and therefore greater speeds and lower voltages may be used. The combination of lower voltages and higher skin effect will greatly reduce shock hazards to the operator from accidental contact with live electrodes. Careful tests to confirm these conclusions ought to be undertaken as soon as possible.

Resistance-welding and flash-welding systems also will benefit as to speed, quality, and greatly reduced cost of equipment, from a tenfold increase in frequency.

Effect of High Core Temperatures on Efficiency and Economy

As far back as 1911 and 1912 MacLaren published his researches demonstrating substantial reductions in core loss at increasing core temperatures.[2] As core temperatures heretofore have been limited to about 90 degrees centigrade to avoid the sludging of oil, now, with the replacement of oil by compressed gases, it becomes possible to operate the transformer cores at temperatures as high as 300–325 degrees centigrade, so as to realize corresponding reductions in core loss and secure great economies in core material by operating the cores at higher frequencies and flux densities than now possible.

These high temperatures are particularly advantageous in the case of those compressed gases (as SO_2) which tend to liquefy at the lower temperatures.

Thermal Screening of Windings

In a compressed-gas design the windings also will be operated at higher temperatures (though not so high as the core temperatures), so as to enable them to carry greater loads per pound. Higher winding temperatures naturally tend to raise the I^2R, but in this system a higher iron-to-copper ratio would be maintained using relatively more flux and fewer turns, and thus the increase in the I^2R due to higher temperature will be small and may be offset by operating the core at a still higher temperature.

With core temperatures of the order of 300 degrees centigrade the winding temperatures should be 100 degrees less, in which case provision must be made for the thermal screening of the windings from the core. Excellent high-temperature materials are now plentifully available for turn and layer insulation and for spacers and strengthening supports, and for screening the windings from the core. Mycalex, asbestos, lava compositions, or ceramic materials in suitable thicknesses easily will withstand a temperature drop of 100 degrees centigrade between core and windings.

Heat-Transfer Procedure

The stream of circulating gas will be heated by the transformer losses as it ascends from the bottom to the top of the transformer. Above the transformer, or in the upper portions of the tank, condensation may be effected by providing a

region of lower temperature or through an external heat exchanger.

The circulation speed of the gas will be high—500–1,000 feet per minute, controlled by a fan or blower.

As the core will operate around 300 degrees centigrade, and there will be a drop of about 100 degrees centigrade through the thermal barrier, the ascending gas will flow over barrier surfaces at a temperature of about 200 degrees centigrade. By virtue of the high rate of flow of the gas, no portion of it will acquire a temperature higher than 150 degrees centigrade.

The hottest parts of the windings may attain a temperature in excess of 200 degrees centigrade, the surface drop probably exceeding 75 degrees centigrade, and the average copper temperature by resistance being of the order of 170 degrees centigrade.

These hypothetical temperature values are chosen as well suited to the use of SO_2 at 50 atmospheres.

As a comparison between the heat-transfer capacity of compressed gas and air at atmospheric pressure, it may be pointed out that SO_2 at 50 atmospheres is about 71 times as efficient as atmospheric air for equal volume. This is based on a specific-gravity ratio of 110:1 and specific-heat ratio of 0.154:0.237, excluding considerations of viscosity and contact resistance. Thus, instead of the 130 cubic feet of air per minute per kilovolt-ampere for 55 degrees centigrade rise allowed in air-blast-transformer practice, only 1.8 cubic feet of compressed SO_2 at 50 atmospheres would be needed.

Supporting of Transformer Tanks

The forces exerted on the tanks by the compressed gas can be taken care of by the combination of:

(*a*). Providing a tank-wall thickness of $^5/_8$ inch.

(*b*). Providing internal braces in the form of tie rods of a nonmagnetic alloy.

(*c*). Locating the tank in an underground pit and filling in gravel and cement between the tank walls and the pit walls to provide support for the tank walls.

Comments on Sulphur Dioxide

If absolutely free from all trace of moisture, SO_2 gas is quite noncorrosive to some metals up to rather high temperatures. It costs only six cents per pound, whereas many otherwise attractive insulating gases are rather expensive. In a metal-sealed transformer tank complete absence of moisture may be maintained. Although more tests are desirable on the effect of temperature and pressure on the corrosive properties of this gas, rough tests indicate that a pressure of 40 atmospheres is entirely safe. At this pressure its dielectric strength is 2,400 volts per mil and the condensation temperature 120 degrees centigrade. At 50 atmospheres its dielectric strength is 2,500 volts per mil and condensation temperature 130 degrees centigrade. Doubtless reliable surface treatments (such as enameling) could be developed to render the metal surfaces immune from attack at much higher temperatures.

In this, as well as in all other gases, condensation of the gas on those portions of the system which need insulation must be prevented by keeping those parts hotter than the condensing temperature of the compressed gas.

Exploratory Designs

Five designs are exhibited in Table II in just enough detail to disclose clearly the *trends* and illustrate the *potentialities* of compressed-gas transformers. Three of the designs (*A*, *B*, and *C* for 80 kv) are for 20,000 kva each, one at 60 cycles, one at 600, and the third at 1,200. Design *D* is for 50,000 kva at 1,200 cycles per second, and *E* for 100,000 kva at the same frequency.

Design *A* (60 cycles per second) has a per kilovolt-ampere weight of 4.2 pounds, which is approximately half that of a conventional oil design, whereas designs *B* and *C* have weights of only 1.05 and 0.82 pounds per kilovolt-ampere, respectively. The full-load efficiencies vary from 99.0 per cent at 60 cycles per second to 99.2 per cent at 600–1,200 cycles per second, and can be made higher if desired. In order to save on critical materials aluminum, instead of copper, is figured on in all of these designs.

Table II. Five Exploratory Compressed-Gas Designs for Power Transformers

	A	B	C	D	E
Rated output (in kilovolt-amperes)	20,000	20,000	20,000	50,000	100,000
Periodicity, N (cycles per second)	60	600	1,200	1,200	1,200
Primary voltage (kilovolts)	80	80	80	200	345
Primary turns (T)	240	160	132	180	200
Magnetic flux (M) (megalines)	126	18.8	11.4	21.0	32.5
Volts per turn	333	500	605	1,110	1,730
Space factor (in winding window)	0.158	0.121	0.110	0.087	0.054
Gross stacking height (inches)	80	65	58	80	100
Primary plus secondary I^2R losses at rated load. Power factor = 1.0 and 170 degrees centigrade (kilowatts)	142	77	54	103	168
Core loss (kilowatts)	42	62	73	184	430
Allowance for stray load loss plus ventilation (kilowatts)	10	15	25	50	75
Total losses, power factor = 1.0 (kilowatts)	194	154	152	337	673
Rated load efficiency, power factor = 1.0 (per cent)	99.0	99.2	99.2	99.3	99.3
Weights					
Laminations	63,000	15,500	12,100	30,600	72,000
Conductors (aluminum)	1,700	900	600	1,200	1,900
All else (including tank, ventilating equipment, insulation, and so forth)	19,300	4,600	3,700	9,200	21,800
Total weight	84,000	21,000	16,400	41,000	95,700
Total weight per kilovolt-ampere	4.2	1.05	0.82	0.82	0.96
Per kilovolt-ampere weight of					
Laminations	3.2	0.78	0.61	0.61	0.72
Conductors	0.085	0.045	0.030	0.024	0.019
Laminations plus conductors	3.3	0.82	0.64	0.63	0.74
Laminations plus conductors in per cent of total weight (per cent)	79	78	78	77	77

These exploratory designs were carried only far enough to disclose trends clearly, to ascertain and check the general consequences of employing periodicities of 600 and 1,200 cycles per second. Attention is called to the fact that the conductor is of aluminum.

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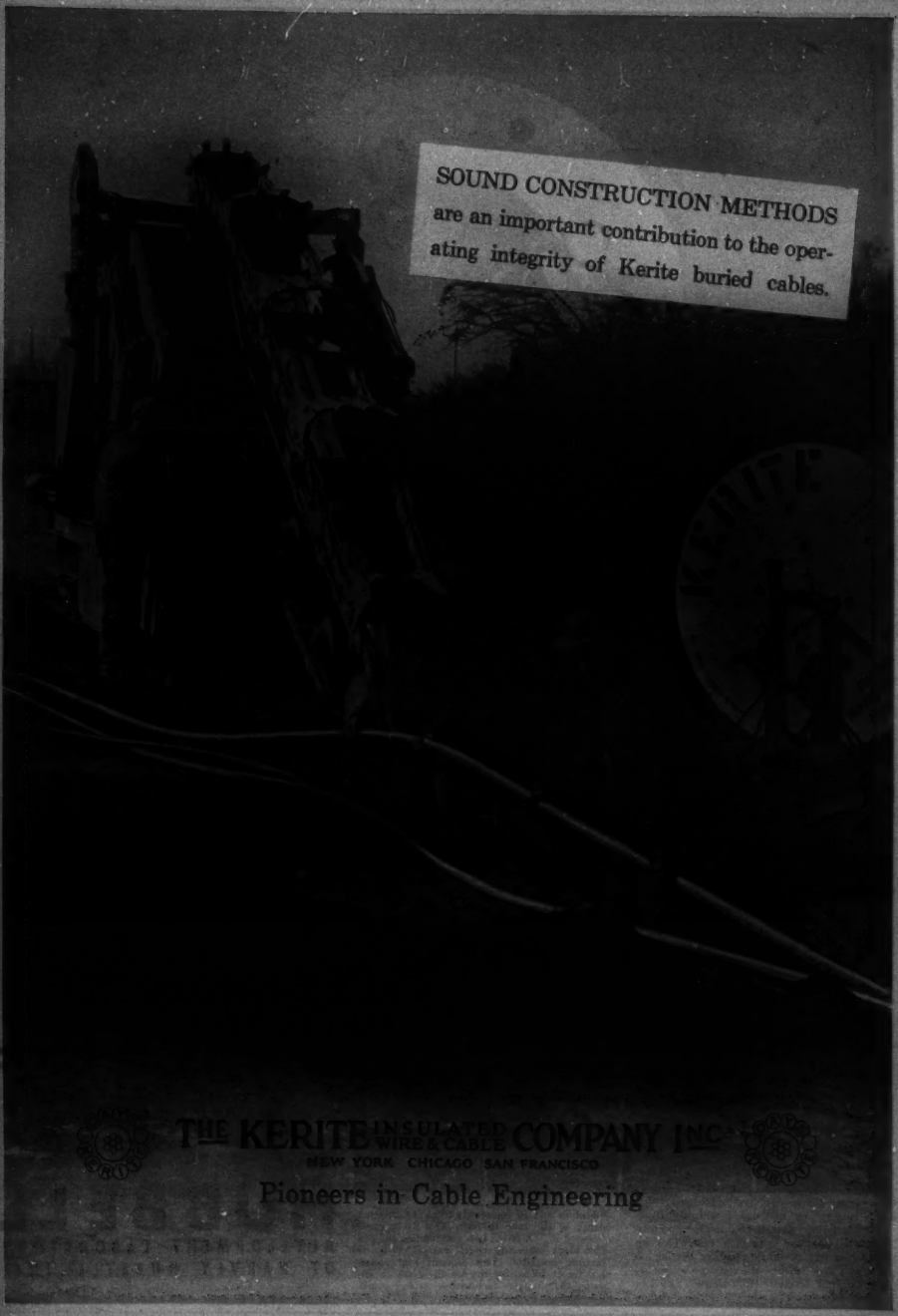
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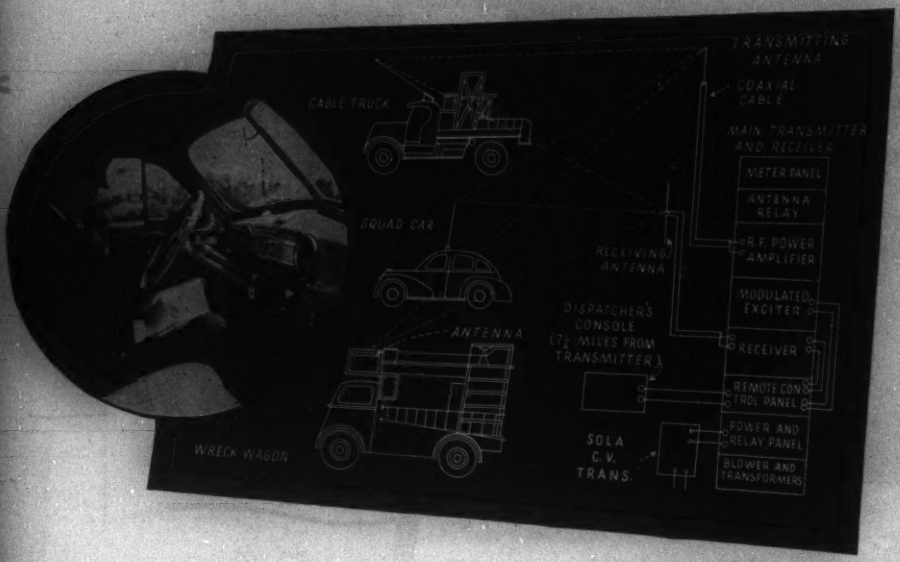

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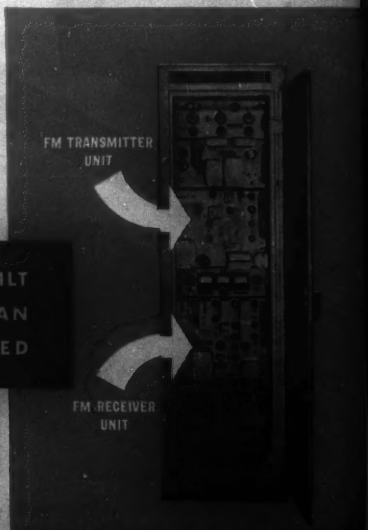
2-frequency
duplex assembly



GENERAL ELECTRIC HAS PLANNED AND BUILT MORE CARRIER-CURRENT EQUIPMENT THAN ALL OTHER MANUFACTURERS COMBINED

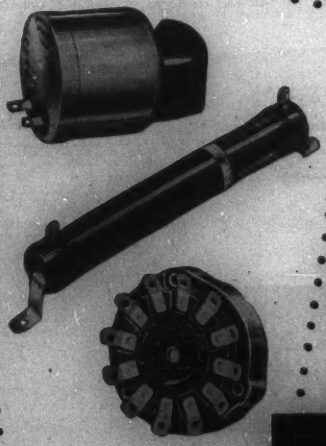
191-55-6080

CARRIER CURRENT

THE NERVE NETWORK OF THE POWER SYSTEM

In Resistance Control

OHMITE EXPERIENCE /MAKES A DIFFERENCE



You get the benefit of Ohmite experience in meeting the varied requirements of innumerable applications . . . in pioneering new rheostat, resistor and tap switch developments . . . in producing the widest range of types and sizes to answer every control need. Add to this, the long service-record of Ohmite Units—their proved ability to function under the most severe operating conditions.

Such experience in resistance control is invaluable to engineers designing new devices to defeat the enemy or planning new products for the postwar era.

Your Answer Book to Resistance Problems

Write on company letterhead for helpful 96-page Industrial Catalog and Engineering Manual No. 40.

OHMITE MANUFACTURING COMPANY

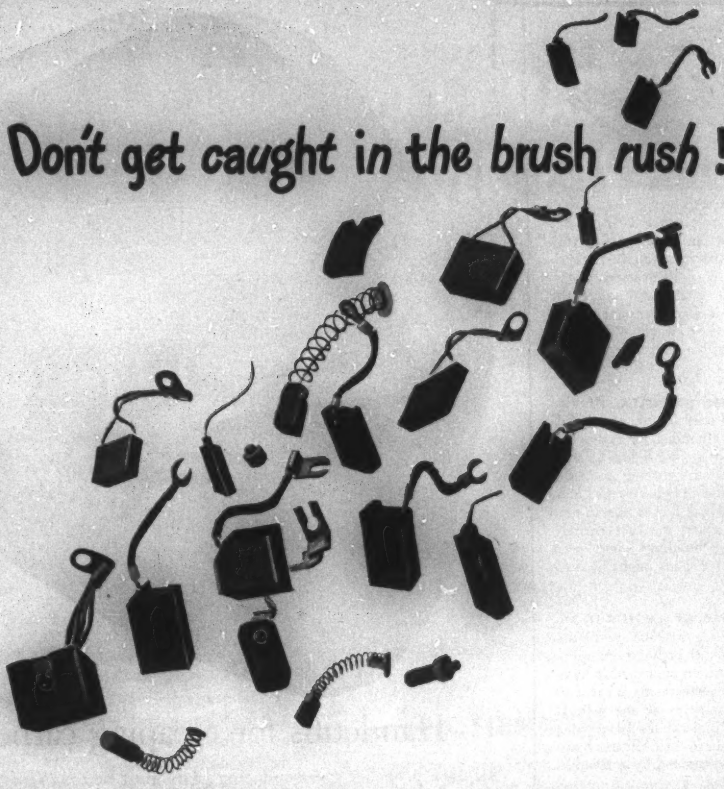
Foremost Manufacturers of Power Rheostats, Resistors, Tap Switches

4863 FLOURNOY STREET ★ CHICAGO 44, U. S. A.

Be Right with OHMITE

RHEOSTATS • RESISTORS • TAP SWITCHES

Don't get caught in the brush rush!



THE fractional horse power brush testing laboratory as well as the Research Laboratories of National Carbon Company, Inc. first made possible the successful operation of brushes on high altitude airplanes. This problem has occupied the major portion of the time of these laboratories for the past few years.

As the heavy war demands upon our brush testing personnel and equipment taper off, the non-war-essential activities of this unique fractional horse power brush testing laboratory are becoming available for testing models of your postwar motors, and determining the brushes for the most satisfactory operation.

We urge you not to wait for the rush, but to submit your test models to us as soon as you can so that our services may be both thorough and on time.

Keep your eye on the infantry . . . the doughboy does it!

NATIONAL CARBON COMPANY, INC.

Unit of Union Carbide and Carbon Corporation

UCC

General Offices: 30 East 42nd Street, New York 17, N. Y.

Division Sales Offices: Atlanta, Chicago, Dallas, Kansas City, New York, Pittsburgh, San Francisco

KEEPING UP WITH

Electricity

BUMPLESS RIDES in trains and automobiles are forecast, because of a new-type stabilizer. Present job of the stabilizer is to make it possible for American tanks to fire with deadly accuracy, even when traveling at full speed over rough terrain. No details until after the war, but it is another of the many Westinghouse wartime developments with peacetime applications.

LIGHTNING UMBRELLA. A wire stretched over the top of a building, then grounded, forms a better protection against lightning than the old-time lightning rod, the Westinghouse High-Voltage Laboratory finds. Effect is like an umbrella, keeping the bolt entirely away from buildings where even the slightest spark might be dangerous.

THIMBLEFUL OF RECTIFICATION. Copper-oxide rectifiers are usually associated with high-current applications, but one type used in high-frequency instruments is rated at one milliampere—at one volt. It is 3/32 of an inch in diameter; a bank of four in their Micarta housing can be covered by a thimble.

OUTDOING THE LAC BUG—Shellac is produced by an Asiatic insect familiarly known as the lac bug. When the greater part of the world's population of lac bugs fell into enemy hands, this important plastic was cut off from us. Westinghouse research men then created synthetic molecules almost identical with the molecules of shellac. This new material is an even better shellac for many uses than shellac itself.

• • •

Let us send you a free copy of the new booklet, "Books by Westinghouse Authors." Titles listed are not only in the fields of Electricity and Electronics—many of them standard texts—but also cover a wide variety of other subjects, from Astronomy to Sales Engineering. Ask for booklet EE 94.

Handcuffs for escaping carbon

Airplane propeller speed-reducing gears must be *tough and strong* to withstand the terrific punishment of long flights over enemy territory.

Westinghouse research engineers have found a way of toughening these gears so that *their former life expectancy is doubled.*

These engineers developed a process of heat-treating the gears in an *Endogas** atmosphere that prevents the escape of carbon from the steel parts.

Ordinarily, in a heat-treating furnace, the carbon-hungry oxygen actually *devours the carbon* on the outer skin of the steel, softening the surface and depositing a layer of scale.

In a furnace employing an Endogas atmosphere, any carbon which may escape from the steel is instantly replaced. The carbon content is undisturbed. Furthermore, no scale is formed—thus reducing, and in some instances, completely eliminating the cost of finish machining of Endogas-treated parts.

Another example of how Westinghouse research helps America outproduce all the Axis powers combined! Westinghouse Electric & Manufacturing Company, Pittsburgh 30, Pennsylvania.

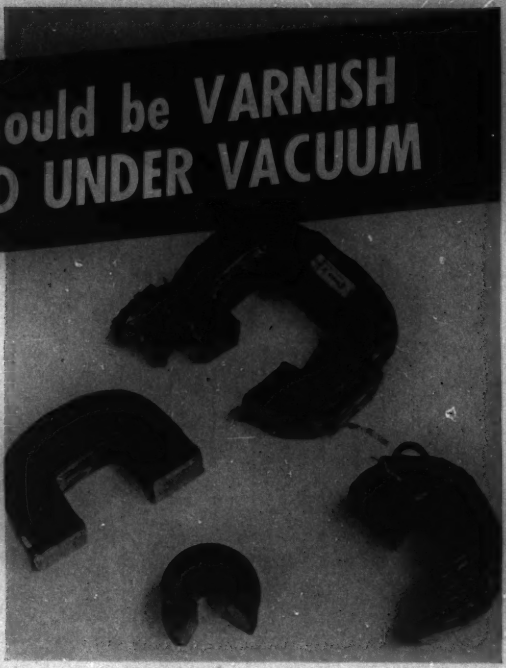
*Trademark Reg. U. S. Pat. Off.

WESTINGHOUSE PRESENTS: *John Charles Thomas, Sunday 2:30, EWT, NBC. Ted Malone, Monday, Wednesday, Friday, 10:15 pm, EWT, Blue Network*

Westinghouse

PLANTS IN 25 CITIES OFFICES EVERYWHERE

Why coils should be VARNISH IMPREGNATED UNDER VACUUM



The photograph at the right illustrates tightly wound fine wire coils which have been treated with varnish under vacuum. Note the firmness at the points where the coils have been cut with a saw. This firmness was achieved by using the proper grade of varnish for deep penetration under vacuum. To further illustrate this point, it was necessary to use a hammer and a chisel in order to break apart a section of the large coil. For maximum penetration of varnish, impregnate coils under vacuum.

Here Are Some of the Advantages

First of all, it is possible through the use of a vacuum to remove air pockets between coil layers which under ordinary atmospheric impregnation would prevent the varnish from penetrating the interiors of the coils. Moisture which was not driven off during preheating will be removed under a vacuum due to the fact that the boiling point of water is greatly reduced at sub-atmospheric pressure. The air and water in coils which are removed under vacuum will be replaced with varnish when the vacuum is broken and atmospheric pressure restored. Those are only a few of the advantages of treating units with varnish under vacuum.

Further information on the treating of electrical units with varnish is contained in DOLPH'S Booklet on "Application of Insulating Varnishes". A copy may be had by making your request on your company letterhead.

Coil Treatment Service

One section of our laboratory contains vacuum equipment having a 12 inch diameter vacuum tank and also modern electric thermo-control ovens. Through the use of these facilities, we are in a position to treat some of your newly designed electrical units which require varnish insulation. Upon completion of this experimental work, a report will be issued covering the several procedures followed and recommendations made accordingly. Of course, this service is offered without any obligation on your part.

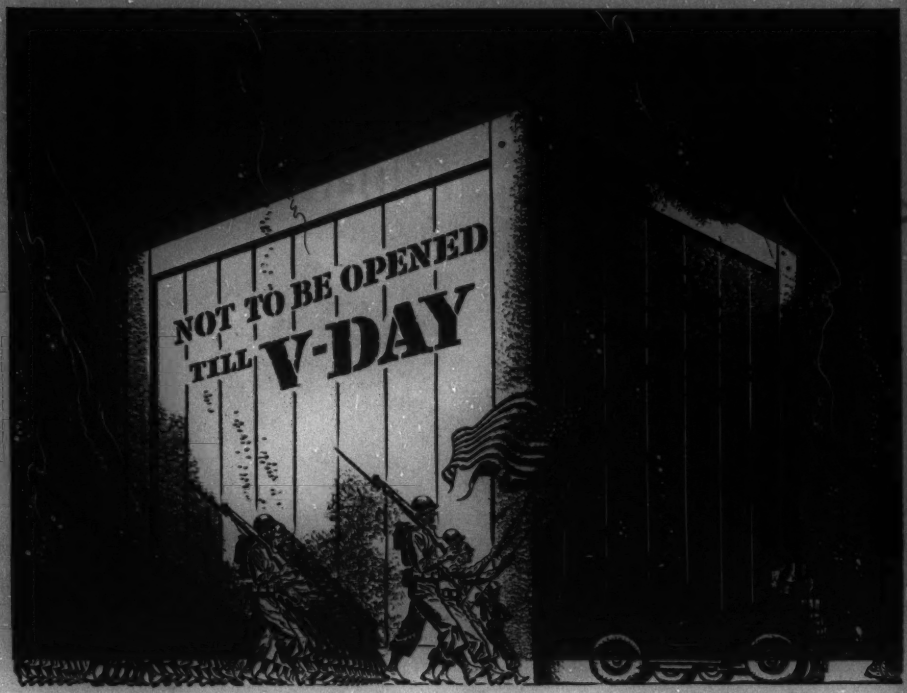
MANUFACTURERS OF
CHINALAK Baking Varnishes
SYNTHITE Baking Varnishes

Dolph's

JOHN C. DOLPH COMPANY

Insulating Varnish Specialists

166-8 EMMETT ST. NEWARK N J



When that Great Day dawns you'll be in the market for new types of components for your electronic devices now in the planning stage. Among your needs will be resistors embodying those characteristics which the new applications demand.

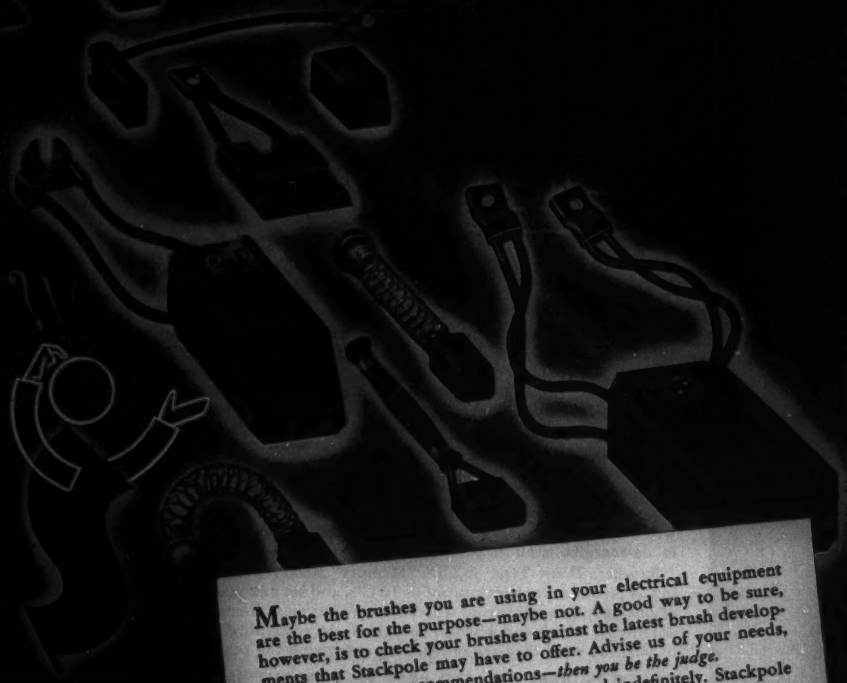
For months, in the midst of war production, the IRC Engineering Staff has been looking ahead—designing, adapting, testing, perfecting—to incorporate in peacetime resistors special features developed for war uses and which will anticipate industry's future requirements.

Yes, "IRC will be ready" to supply resistors of *all types* on a mass production basis. . . . In the meantime and without obligation, our Research Engineering Department invites you to discuss with them (confidentially, of course) any resistor problems connected with your peace-time production.

PREFERRED FOR PERFORMANCE · IRC · FIXED RESISTORS

INTERNATIONAL RESISTANCE CO.

HOW TO BE SURE ABOUT YOUR BRUSHES



Maybe the brushes you are using in your electrical equipment are the best for the purpose—maybe not. A good way to be sure, however, is to check your brushes against the latest brush developments that Stackpole may have to offer. Advise us of your needs, let us submit our recommendations—*then you be the judge.*

For brush problems don't stay answered indefinitely. Stackpole brush engineering moves too fast for this. Units that may have been "best" yesterday, may be outmoded in the light of today's developments. It costs you nothing to check on this score—and the Stackpole recommendations may spell new efficiency for your product.

Stackpole Brushes are sold only to makers of original equipment—not direct for replacement purposes.

STACKPOLE CARBON COMPANY, ST. MARYS, PA.

BRUSHES and CONTACTS
All carbon, graphite, metal, and carbon-graphite types

RARE METAL CONTACTS

BEARINGS

WELDING CARBON PRODUCTS

BRAZING BLOCKS · CARBON PIPE

PACKING, Piston and SEAL RINGS

CARBON REGULATOR DISCS

STACKPOLE ELECTRONIC COMPONENTS
Iron Cores · Switches
Fixed and Variable Resistors

STACKPOLE

PIONEERS OF BRUSH PROGRESS

OPERATES POSITIVELY FROM A MOMENTARY IMPULSE

A SMALL "MEMORY-TYPE" RELAY

with **R-F INSULATION**

Originally designed for aircraft services, this new Struthers-Dunn 50XBX "Memory" Relay is ideally suited for numerous other applications as well. It is of two-coil, latch-type construction, having radio frequency insulation on its double-pole, double-throw main contacts. These contacts operate immediately upon receipt of a momentary impulse from a push button, limit switch, or any other source of brief or extended impulses.

The coils are practically universal in that they will operate on voltages as low as 12-volts D.C. Since they are in the circuit only momentarily, they cannot overheat on much higher voltages, nor will they hum or overheat on A.C. as each coil may be connected to de-energize itself as soon as it has performed its function.

Struthers-Dunn Type 50XBX "Memory" Relays will operate in any position, are shock-proof to 10 G's, and set new standards of efficiency on applications where the contacts must "remember" unfailingly which coil was last energized—by remaining latched in position until they are released by energizing the other coil.

STRUTHERS-DUNN, INC., 1321 ARCH ST., PHILADELPHIA 7, PA.

ONE OF THE FAMOUS

STRUTHERS-DUNN

5,288 RELAY TYPES

DISTRICT ENGINEERING OFFICES: ATLANTA · BALTIMORE · BOSTON · BUFFALO · CHICAGO · CINCINNATI · CLEVELAND DALLAS · DENVER · DETROIT · HARTFORD · INDIANAPOLIS · LOS ANGELES · MINNEAPOLIS · MONTREAL NEW YORK · PITTSBURGH · ST. LOUIS · SAN FRANCISCO · SEATTLE · SYRACUSE · TORONTO · WASHINGTON

WHERE TOMORROW MEETS TODAY

Up there above the clouds the Dreams of Tomorrow are being proven today

SOARING COMBAT PLANES sing a song of the future! In equipment and efficiency they far outstrip normal peace-time ambitions. They are born of the grim challenge of war for new and ever-improved electrical design.

Vision and inventive genius are required to originate such new developments, and in this field Small Electric Motors (Canada) Limited have been privileged to make important scientific contributions. Out of the experience gained today by forward-looking firms like this, substantial benefits will accrue to the world of tomorrow.

At the moment, Small Electric Motors is in full production for Victory but in the post-war field of electrical equipment the influence of this aggregation of creative engineering minds will also be recognized for specialized services of a high order.

DESIGNERS AND MANUFACTURERS Of All Types of Precision Electrical Apparatus Including:

D.C. & A.C. Motors for Specialized Purposes
Aircraft Generators
Aircraft Engine Starters
Alternators
Motor Generators
Electric Pumps
Motors with Governors
Gyros, etc.

1-44

SMALL Electric Motors
(CANADA) LIMITED

LEASIDE • TORONTO • CANADA

This NEW Sturdy, Smaller Transtat AC Voltage Regulator OFFERS INCREASED DESIGN POSSIBILITIES!

The new TH 2½A Transtat A. C. Voltage Regulator is half the size and less than half the weight of the smallest previous TH Transtat. When used as a dual unit, a further space saving is made possible by base-to-base mounting. In attaining this extreme compactness, AmerTran also introduced several mechanical innovations: the unique die cast brush arm with its generous heat dissipating surface; smooth commutator with solid insulation between segments; the operating shaft that can be quickly changed for table, panel or gang mounting; the Phenolic Thermosetting Plastic Base with its terminal barriers and other features.

Yet the TH-2½A Transtat's conservative rating is a working rating—output voltages are full load voltages. Exciting current is only 0.06 amperes. Control throughout working range never exceeds 0.4 volt increments. And like its larger brothers, it cannot disturb power factor, distort wave form or interfere with radio reception. Investigate its possibilities in your apparatus today.

Write for Bulletin 171-01

TYPE TH-2½A TRANSTAT FOR SINGLE PHASE OPERATION					
	VA	Frequency	Input Volts	Output Volts	Output Amperes
		50° Centigrade Rise			
Nominal	300	50/60	115	0-115	2.6
Maximum	340	50/60	115	0-130	2.6
TYPE TH-2X-2½A TRANSTAT DUAL UNIT, OPEN DELTA CONNECTED FOR THREE PHASE REGULATION					
		50° Centigrade Rise			
Nominal	520	50/60	115	0,115	2.6
Maximum	590	50/60	115	0-130	2.6

AMERICAN TRANSFORMER COMPANY, 178 Emmet St., Newark 5, N. J.

AMER-TRAN

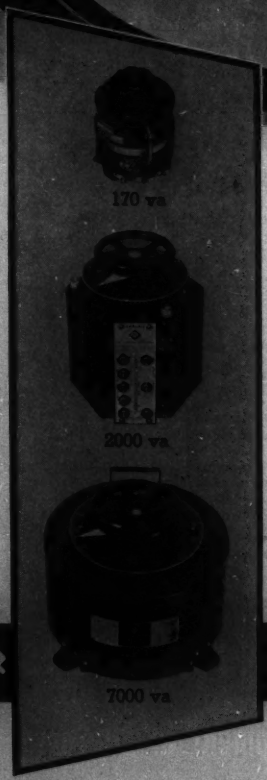
Pioneer Manufacturers of Transformers, Reactors and Rectifiers for Electronics and Power Transmission

AMERTRAN

VARIACS

FOR

VOLTAGE CONTROL



THE VARIAC . . . the *original* continuously adjustable, manually operated a-c voltage control . . . has these features:

- **SMOOTH CONTROL** — The VARIAC may be set to supply any predetermined output voltage with absolutely stepless variation.
- **HIGH EFFICIENCY** — Exceptionally low losses both at no load and at full load.
- **HIGH OUTPUT VOLTAGES** — VARIACS supply output voltages 17% higher than line voltage.
- **LINEAR OUTPUT VOLTAGE** — Output voltages are continuously adjustable from ZERO by means of a 320 degree rotation of the knob.
- **SMALL SIZE** — VARIACS are smaller than any other voltage control of equal power rating.
- **CALIBRATED DIALS** — VARIACS are supplied with reversible dials which read directly in output voltage both from zero to line voltage and from zero to 17% above line voltage.
- **ADVANCED MECHANICAL DESIGN** — Rugged construction; no delicate parts or wires; two or more units may be ganged on the same shaft for multi-phase operation.

VARIACS are stocked in nine models with power ratings from 170 va to 7000 va; prices range between $10.00 and $100.00.

Because all of our facilities are devoted to war projects, VARIACS are available at present only for War work; all orders must have a priority rating.

VARIACS are made *only* by General Radio

GR **GENERAL RADIO CO.** Cambridge 39, Mass. NEW YORK CHICAGO LOS ANGELES

● **WRITE FOR BULLETIN 886**

WRITE TODAY!

GET ACQUAINTED NOW WITH THE RESISTORS OF TOMORROW!

HERE'S THE LATEST DATA...

on the most up-to-the-minute resistors

Time and again, during the past seven years, Sprague Koolohms have demonstrated convincingly their ability to handle jobs that old-style, conventional wire-wound resistor types could not handle satisfactorily.

One after another, they have proved their superiority in practically every essential characteristic — from faster heat dissipation with resulting use up to full rated wattage values, to better performance under humid conditions.

Whether for war use today, or for greater efficiency for your post war product tomorrow, it should pay you to become fully acquainted with this remarkable resistor development. Write for this big new catalog today!

The ONLY Resistors wound with *CERAMIC INSULATED WIRE!

Resistor types in this new catalog include:

Wire-wound power types, 5- to 120-watts. Inductive and non-inductive.

Hermetically-sealed wire-wound types, 10- to 120-watts.

Wire-wound bobbin types.

Voltage divider sections, 10-, 15- and 25-watts.

Hermetically-sealed precision meter multipliers resistors.

Megomax hermetically-sealed high-voltage, high-temperature resistors.

SPRAGUE ELECTRIC COMPANY, Resistor Division
(Formerly Sprague Specialties Co.) NORTH ADAMS, MASS.

SPRAGUE KOOLOHM RESISTORS

The Greatest Wire-Wound Resistor Development in 20 Years

Sangamo Capacitors Can Take It!

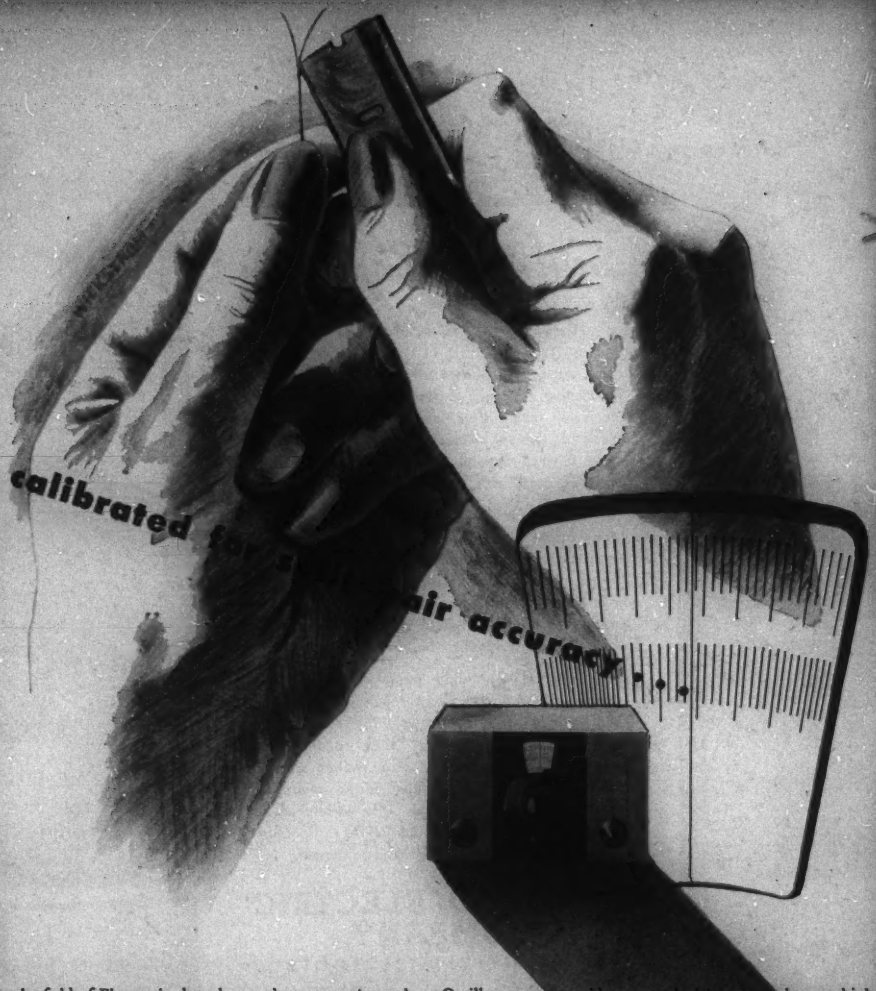
Mica capacitors play a vital part in the correct functioning of many types of equipment. Radio receivers, transmitters, hearing aids, underwater sound equipment, induction heating, and many other devices depend upon the faithful performance of capacitors to enable them to function properly.

Many applications of capacitors in these various equipments necessitate a wide range of sizes, shapes, voltages, and current carrying ability in order that the proper capacitor may be used, depending upon the physical space limitations and electrical characteristics to be met.

As illustrated, Sangamo manufactures a large variety of capacitors from the small wire lead type having a body size of only 23/32" in length, 15/32" in width, and .20" thick to the large ceramic case type capable of operating at voltages up to 35,000 and handling large amounts of radio frequency current. This wide variety of capacitors insures the availability of the proper unit for almost any mica capacitor requirement.

SANGAMO ELECTRIC COMPANY

SPRINGFIELD, ILLINOIS



As the field of Electronics broadens and new, more complex equipment goes into service the need for more accurate test and measuring instruments becomes greater. The war has lent great impetus to the progress of Electronics and has accordingly accellerated the development of Electronic instruments. Into the past two years have been crowded a normal ten years of technological progress.

Today the most advance developments are not being released for general use. However, today is not too soon for you to make your plans for post-war activity. And, along that line, you should make note of the fact that -*hp*- engineering is in the vanguard of electronic instrument developments.

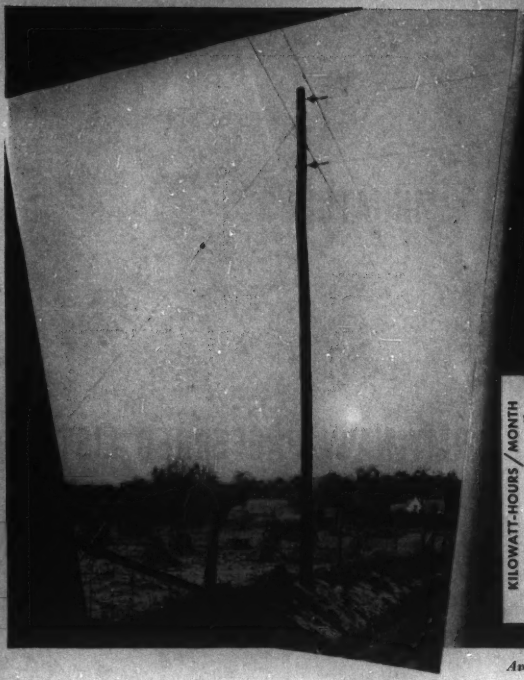
Oscillators to test wide range television channels, new high frequency signal generators, special signal generators for F. M. use, new vacuum tube voltmeters, all providing split-hair accuracy for more exacting measurements and ruggedly constructed to perform in the field under circumstances of war, are examples which merely hint of the better things to come.

-*hp*- engineering is at your service, whether your problem is immediate or for post-war. Write today, there is no cost or obligation. Direct Canadian inquiries to Atlas Radio Corporation, 560 King Street West, Toronto 2, Canada.

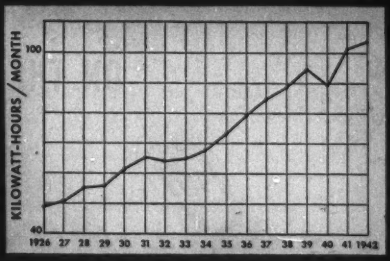
HEWLETT-PACKARD COMPANY

Box 927 Station A · Palo Alto, California

927



RURAL DEMAND TOPS 100 *kwh/month*



Average monthly consumption in non-irrigated rural areas

Climbing from less than fifty kilowatt-hours per month in 1926 to well over a hundred today, rural power consumption promises to hasten obsolescence of even the latter figure. For, included in that average are many young rural lines, whose customers have not been able to equip themselves with electrical appliances since the war began. Others are just becoming accustomed to having electrical help at hand.

Purchasers of Aluminum Cable Steel Reinforced will recall that Alcoa engineers have always preferred not to recommend conductors smaller than Number 4 A.C.S.R. Alcoa's supervisors, close to the feel of things in the field, prophesied that farm operators would adopt electrical help eagerly. Low conductivity wires would limit the power they could take from their lines.

Consult with Alcoa engineers on the sizes of A.C.S.R which will provide current-carrying capacities permitting future load expansion. A.C.S.R. has the high strength and durability required in modern line construction. ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh 19, Pennsylvania.

ALCOA A·C·S·R

ALCOA

The 17 RCA Miniatures shown on this page—all of them on today's Army-Navy Preferred List of Vacuum Tubes—are:

1A3 —H-F diode	6AG5 —R-F amplifier pentode
1L4 —R-F amplifier pentode	6AL5 —twin diode
1R5 —pentagrid converter	6AQ6 —Duplex-diode High-Mu triode
1S5 —diode-pentode	6C4 —H-F power triode
1T4 —R-F amplifier pentode	6J4 —U-H-F amplifier triode
3A4 —power amplifier pentode	6J6 —twin triode
3A5 —H-F twin triode	9001 —Sharp cut-off U-H-F pentode
3S4 —power amplifier pentode	9002 —U-H-F triode
	9003 —Super-control U-H-F pentode

TINY tubes like these—*every single one of them developed by RCA*—were destined for the spotlight—thanks to your recognition of their possibilities.

The spotlight picked them up first in June, 1940, when the "Personal Radio" was announced—the history-making portable designed around RCA's staunch little quartet, Miniatures 1R5, 1S4, 1S5, and 1T4.

War found Miniatures instantly available for overseas service—for example, in such equipment as the para-trooper's air-borne "Handie-Talkie."

Once Victory is won, it will be our privilege to work with you designers so that, together, we may play our continuing parts in miniature tube type development and use for peace-time purposes. We look forward to that day. And we will gladly advise you now which tubes—Miniatures, and others—will most likely be on RCA's post-war list of "Preferred Tube Types." If you will write to RCA Commercial Engineering Section, 722 South 5th St., Harrison, N. J.

The Magic Brain of all electronic equipment is a Tube and the fountain-head of modern Tube development is RCA.

BUY WAR BONDS

RCA

RADIO CORPORATION OF AMERICA

RCA VICTOR DIVISION • CAMDEN, N. J.

Micromax Recorder at left shows temperature of 6 points in stator, and also of exciter air and outlet water of the hydrogen cooler of a generator. Recorder at right shows temperature of the field. Watching these 9 temperatures is essential when carrying heavy load, though Recorders will also sound alarms if any one temperature exceeds a predetermined point.

"OVERLOADED" GENERATORS

Need This Micromax Field and Stator Protection!

Loading of electrical generators on the basis of the temperatures of their stators and rotors is a practice which many power companies are now planning to use. Special tests have been outlined* to determine the amounts of load which may be added, under specific conditions, to that given as maximum on the nameplate. Here are some of the factors to be considered:

1. Each generator is a separate problem.
2. Nameplate data may provide unnecessarily large safety factor for load swings, unbalanced phases, etc.
3. Ambient temperature may be less than nameplate specifies.
4. Power factor may be higher than specified.
5. Change in terminal voltage may permit greater output.
6. When starting from low temperature, a generator can carry short-time excess load because of its own temperature lag.
7. In emergencies and for short peaks it may be more economical to operate at extraordinary temperature and thus age the insulation at an abnormal rate, rather than to provide the additional rated capacity for short-time loads.

* From AIEE Miscellaneous Paper 43-93, "Interim Report on Emergency Measures to Increase Output of Generating Equipment and Systems", June 1943, available at 65¢ from AIEE, 33 W. 39th St., New York City 18.

When a generator is loaded on the basis of temperature, we can supply its operator with complete temperature readings by means of two instruments—a Micromax Stator Temperature Recorder and its companion, a Rotor Recorder.

The Stator Recorder shows the temperature of 6 points, and of incoming and outgoing cooling medium. It sounds an alarm if a peak temperature is reached.

The Rotor-Temperature Recorder measures the resistance of the entire field and records it as temperature. Devised about 15 years ago, it has been less used than the Stator Recorder, for the reason that not every generator normally needs both instruments. As load becomes abnormal, or unfavorable power factor conditions occur, however, this instrument has come increasingly into use and under present-day conditions is rapidly becoming standard equipment for large generators.

Both instruments are described in Catalog N-33-161, available on request. If you have a specific instrumentation problem in mind, please describe it and an L&N engineer will gladly try to help solve it.

LEEDS & NORTHRUP COMPANY, 4902 STENTON AVE., PHILA. 44, PA.

LEEDS & NORTHRUP

MEASURING INSTRUMENTS · TELEMETERS · AUTOMATIC CONTROLS · HEAT-TREATING FURNACES

Jrl Ad N-33-161(5)

depends on me!

A Slogan For Every American

FIBERGLAS*
Electrical Insulation Tapes

Permit substantial space and weight savings in

FLUORESCENT
Ballast Coil
Design and Construction

• • •

Smaller, lighter, sign-lighting control and signal transformers also possible

Fiberglas tapes are available in tight and medium weaves, in all widths commonly required for insulating electrical products, in thicknesses of .003", .005", .007", .010" and .015".

Do you have a critical space problem—in ballast coils, transformers or other electrical equipment—where bulky insulations on the wire and around the coils are major factors in establishing the size and weight of your design? Then don't overlook the exceptionally low space factor of Fiberglas insulation—particularly tapes.

If space is at a premium—remember that a thinner inorganic Fiberglas tape will do the job of a thicker organic tape. And, too, Fiberglas tape will take much less space than equivalent inorganic materials. Because Fiberglas tape has superior tensile strength, it also permits a tighter, more compact wrapping of coils.

Besides low space factor and less weight in designed product, Fiberglas insulations have other advantages, for example:

• ***High thermal resistance.*** Although total effectiveness of insulation depends on impregnation, Fiberglas forms an insulating *base* which does not deteriorate from heat far above that encountered in electrical apparatus.

• ***No change with age***—of particular importance in stand-by equipment, or where equipment stands idle over long periods of time. The glass fibers do not deteriorate, even though moisture should penetrate the outer impregnation.

• ***Not affected by moisture or most acids.*** Again, total effectiveness depends on impregnation, but should impregnating varnish fail, moisture will not disintegrate the glass fibers—and often will permit motor to be dried out and run again.

WHAT IS FIBERGLAS?

Fiberglas is the trade name for glass in the form of fine fibers or filaments. These fibers are twisted into yarns, served on wire, woven into tapes and cloths, braided into sleevings, or twisted into cords—untreated or treated—to fill every electrical insulation need.

Fiberglas electrical insulations are immediately available in all the forms and sizes used in the electrical industry. For complete information, write *Owens-Corning Fiberglas Corporation, 1859 Nicholas Building, Toledo 1, Ohio; in Canada, Fiberglas Canada, Ltd., Oshawa, Ontario.*

ARMY E NAVY

FIBERGLAS
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ELECTRICAL INSULATIONS

YARNS • TAPES • CORD • SLEEVING • CLOTH AND OTHER FORMS

On Every Fighting Front

the Army Gets its Message through with Copperweld WIRE

The countless miles of Copperweld Wire that are serving in every battle zone have demonstrated for all the world to see, the dependability of this product.

Copperweld has the best electrical conductance of any high strength conductor—is 2 to 3 times stronger than hard-drawn copper wire—has greater tensile strength than any wire of comparable electrical properties. Pliable, easily handled, light in weight, economical in cost, only Copperweld combines the high strength and ruggedness of steel with the conductivity and permanence of copper.

War's use of Copperweld has developed a number of new wrinkles in its application that may be helpful in improving your peacetime installations. Our engineers will gladly make this new knowledge available to you in your planning for tomorrow.

COPPER WELDED TO A CORE OF HIGH STRENGTH ALLOY STEEL

COPPERWELD STEEL COMPANY • Glassport, Pa.

For almost 30 years we have been making and constantly improving Copperweld—have upped the ultimate tensile strength from 80,000 pounds per square inch to 140,000; and then by using still higher strength alloy steel this figure has been increased to 180,000.

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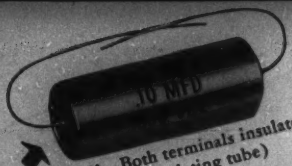
FLIES OVER OUR GLASSPORT PLANT
FOR EXCELLENCE IN PRODUCTION OF COPPERWELD WIRE

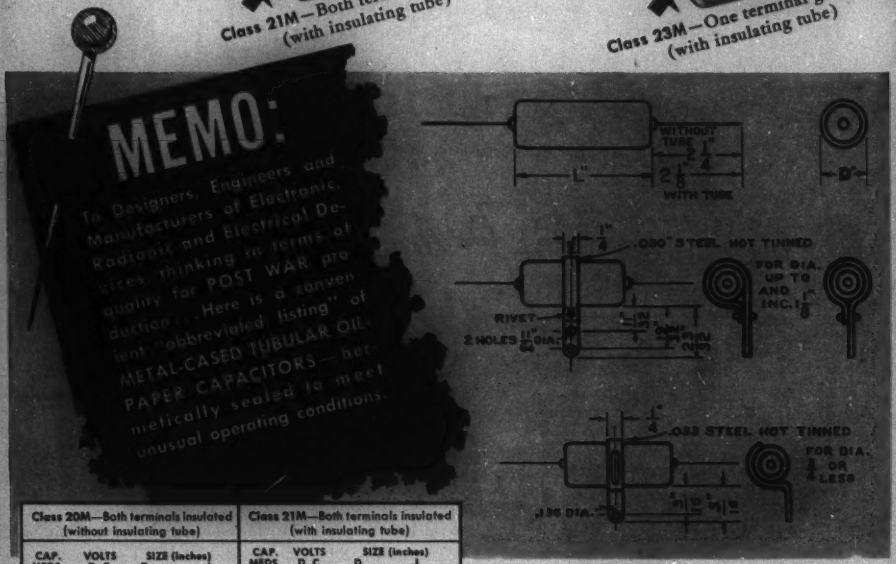


Class 20M—Both terminals insulated (without insulating tube)

Class 22M—One terminal grounded (without insulating tube)

Class 21M—Both terminals insulated (with insulating tube)

Class 23M—One terminal grounded (with insulating tube)


MEMO:
To Designers, Engineers and Manufacturers of Electronic, Radionic and Electrical Devices: Thinking in terms of quality for POST WAR production . . . Here is a convenient "abbreviated listing" of METAL-CASED TUBULAR OIL-PAPER CAPACITORS—hermetically sealed to meet unusual operating conditions.
WITHOUT TUBE
WITH TUBE
L"
D"
.030" STEEL HOT TINNED
FOR DIA. UP TO AND INC. 1"
RIVET
2 HOLES
.032 STEEL HOT TINNED
FOR DIA. 1/2 OR LESS
.136 DIA.

Class 20M—Both terminals insulated (without insulating tube)			
CAP. MFDS.	VOLTS D. C.	SIZE (inches) D.	L
.001	1000	1/2	1-3/16
.0025	1000	1/2	1-3/16
.005	1000	1/2	1-3/16
.005	600	3/8	15/16
.01	600	3/8	1-3/16
.02	600	1/2	1-1/16
.05	600	9/16	1-5/16
.1	200	9/16	1-13/16
.25	200	3/4	1-7/8
.5	200	1	1-13/16

Class 21M—Both terminals insulated (with insulating tube)			
CAP. MFDS.	VOLTS D. C.	SIZE (inches) D.	L
.05	800	11/16	1-5/8
.1	800	13/16	1-7/8
.1	600	11/16	1-3/4
.25	600	13/16	2-5/16
.25	400	13/16	2-5/16
.5	400	1-1/16	2-5/16
1.	400	1-1/16	3-15/16
1.	200	1-1/16	3-3/16
1.5	100	1-1/16	3-3/16
2.	100	1-5/16	2-11/16

Class 22M—One terminal grounded (without insulating tube)			
.0075	1000	1/2	1-1/16
.01	1000	1/2	1-1/16
.05	1000	5/8	1-13/16
.5	600	1	2
1.	600	1	3-5/8

Class 23M—One terminal grounded (with insulating tube)			
.1	1000	13/16	2-1/16
.25	1000	1-1/16	2-1/2
.5	1000	1-7/16	2-13/16
.5	800	1-1/16	3-1/16
1.	800	1-7/16	3-1/4

(Standard Capacity Tolerance on the above units is ± 20%. Closer or wider tolerances may be obtained if required.)

Standard or Special Units to Meet Every Need

FAST Capacitors are produced in many types and sizes in standard or special designs. We can supply paper capacitors—oil or wax impregnated—rectangular or tubular—in sizes from the smallest to the largest.

This line of FAST Capacitors have containers made of brass with a heavy tin dip. The terminals are made with bushings of NEOPRENE and BAKELITE and are painted with glyptal. They have excellent stability over a wide range of temperatures and frequencies—will pass recognized thermal and salt water immersion tests.

Inquiries are particularly invited from organizations planning to build that *better* equipment for the new day ahead. Please feel free to call us on any capacitor problems.

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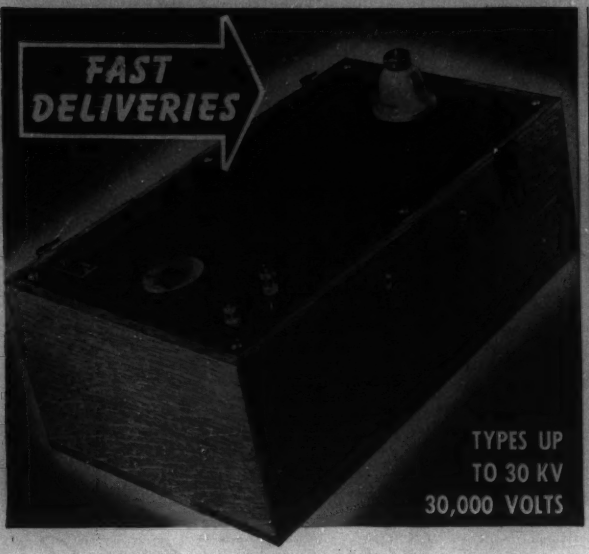

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Kilovoltmeter Multipliers

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Corona-protected High-Voltage Resistors

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Special Apparatus for Any High-Voltage Measuring Requirement

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In addition to its standard line, Shallcross likewise produces regularly a wide variety of "tailor-made" Kilovoltmeters and high voltage Meter Multipliers to match individual requirements. Write for details or engineering recommendations.

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5. Tuning systems
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Location: At our Camden, N. J. plant.

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Security: When you work at RCA, you can be sure you are with a solid organization—25 years in the field, and today more progressive than ever.

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RCA VICTOR DIVISION • CAMDEN, N. J.

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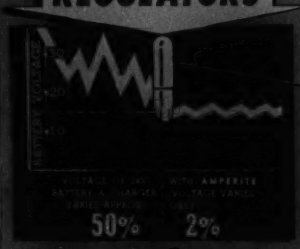

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Millions of Aerovox capacitors are in daily use, especially for electric refrigerators. And Aerovox, through its many jobbers, makes certain that proper replacements are available to safeguard the good will of many equipment manufacturers. ● Write for data.

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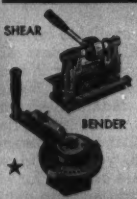

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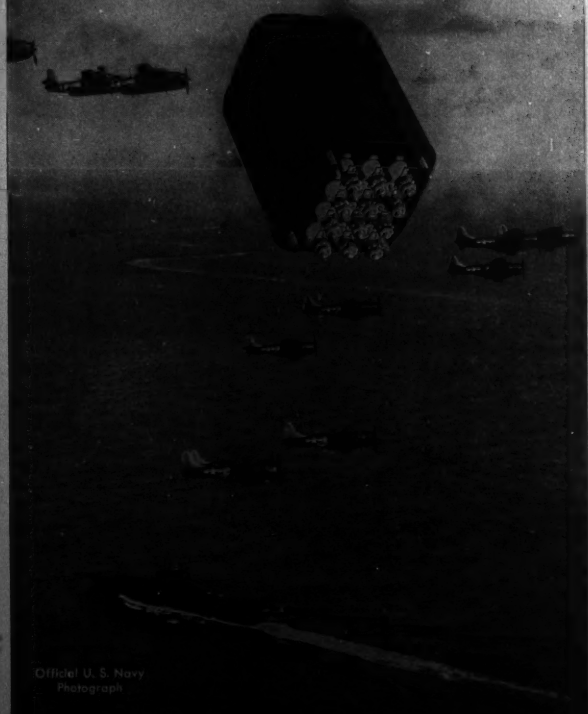

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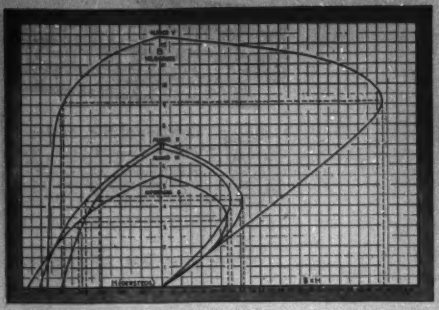

IMPORTANT CURVES

During our many years of service to industry in designing and manufacturing permanent magnets, we have conducted hundreds of tests. From the result of these tests we have been able to plot charts and nomographs for taking much of the guess out of magnet design.

The one shown above—"Typical Demagnetization and Energy Product Curves"—is used constantly by our own engineers in designing magnets from the various proved alloys. If you are designing your own magnets, these curves should be useful, particularly as they are accompanied by an instructive pamphlet—"Permanent Magnet Design."

Send for the chart and pamphlet. Try designing your magnets. We'll be glad to check your results.

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Send for the chart shown above; also for a copy of "Permanent Magnet Design"

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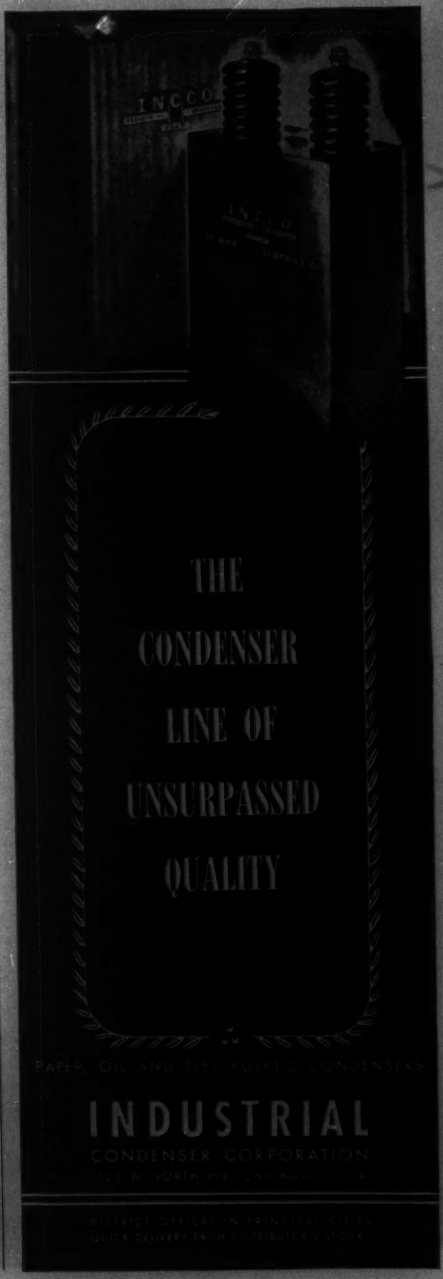

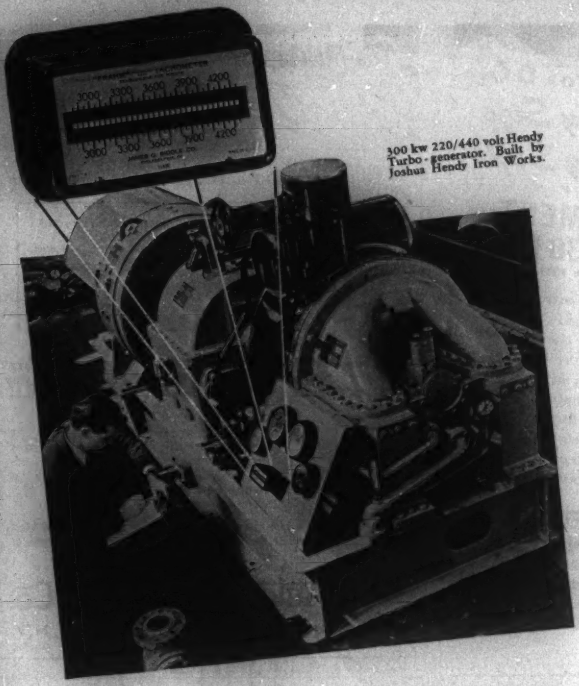

300 kw 220/440 volt Hendy Turbo-generator. Built by Joshua Hendy Iron Works.

. . . making "ASSURANCE DOUBLY SURE" with the "FRAHM" RESONANT-REED TACHOMETER

In the modern turbo-generator, uniformity of speed must be maintained over the entire range of no-load to overload conditions.

The Hendy unit shown above has a carefully designed and precisely built governor to assure uniform speed under widely varying load conditions. As a double check, however, Frahm Resonant Reed Tachometers are used on Hendy and other well-known turbo-generators, both large and small, to provide the operator with constant proof of turbine speed. Manufacturers select Frahm instruments for this service because of their simplicity of construction, ease of installation and freedom from maintenance.

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For a complete description of Frahm Tachometers together with list of types and ranges commonly supplied, write for Bulletin 1590-EE. The instrument shown above is listed in Bulletin 1740-EE.

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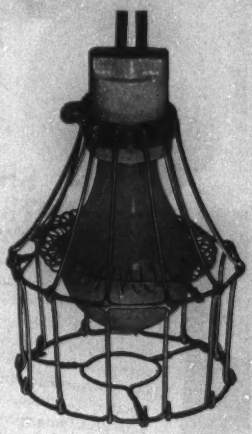

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They are approved by Fire Underwriters.

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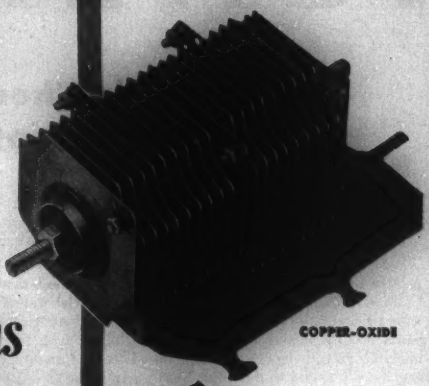

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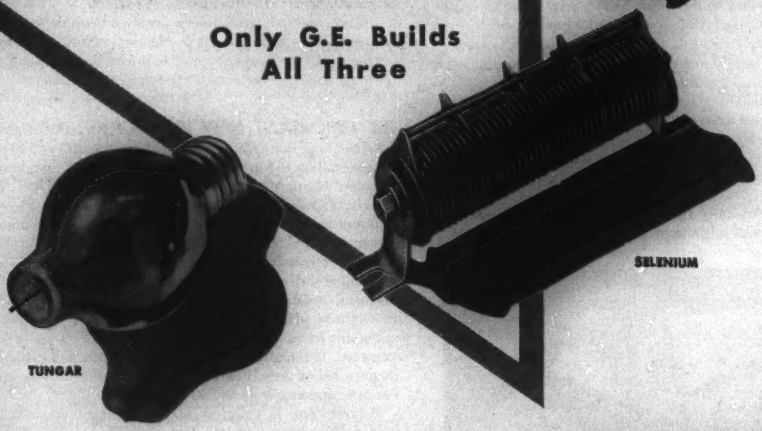

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GENERAL ELECTRIC

POLYETHYLENE

A "Carbide Chemicals" Production Achievement for the Navy

Important New Plastic Has Many Unusual Properties

A little over two years ago, the U. S. Navy learned that Carbide and Carbon Chemicals Corporation in collaboration with an associate company, The Linde Air Products Company, had developed a high pressure synthesis of a new material, Polyethylene, and it was found that this material was exactly suited to meet the Navy's requirements of an insulation for coaxial cable used in radar equipment.

At the Navy's request, these two companies, working together but entirely independent of anyone else, designed in their own Engineering Department and built with their own Construction Organization a plant to produce polyethylene by a process different from any other commercial polyethylene process.

Within thirteen months from the date the project was authorized, this plant was producing at 180 per cent of rated capacity.

At the conclusion of the first full year of production the Navy Department told the plant:

"One year ago your plant commenced the production of polyethylene, a component of radio cable essential to the efficiency of electronic communications units and, therefore, vital to the success of naval operations. Production for the year has equalled 240 per cent of the rated output for the facilities. Everyone engaged in developing the product, planning, engineering, and managing the plant, and each of you engaged in producing polyethylene may be justly proud of a valuable contribution to the war effort."

Today, approximately two years after Carbide was given the assignment, this plant is producing polyethylene at 600 per cent of rated capacity and is providing the Navy's requirements of this material for use in coaxial cable.

THE IMPORTANT NEW PLASTIC! Polyethylene resins have the most favorable electrical characteristics of any plastic material for use in this electronic application. In addition, this new plastic material has many other exceptional characteristics, which suggest widespread application in many different fields. Polyethylene plastics are tough and impact-resistant. They are inherently flexible and extensible. They have an extremely low water vapor transmission coefficient and will absorb an unusually low percentage of water. Their chemical resistance is outstanding. Polyethylene is one of the lightest plastics, so light that it will float in water. It maintains its valuable properties over a wide range of temperature. It remains usable at temperatures lower than 90 degrees below zero, Fahrenheit, and is sufficiently rigid for use in temperatures up to 230 deg. F.

Polyethylene is colorless and translucent as originally manufactured but it can be formulated to produce colored products of exceptionally high lustre. These products can be fabricated by standard processes on existing plastics equipment.

Molded and extruded products, cloth coatings, flexible sheeting and film, and monofilaments are among the polyethylene plastic products which will be available in the future.

Polyethylene plastics are now restricted to applications covered by WPB Limitation Order No. 348. Technical data and samples for controlled end uses can be obtained by manufacturers with plastic-processing equipment by writing Department 1.

Plastics Division

CARBIDE AND CARBON CHEMICALS CORPORATION

Unit of Union Carbide and Carbon Corporation

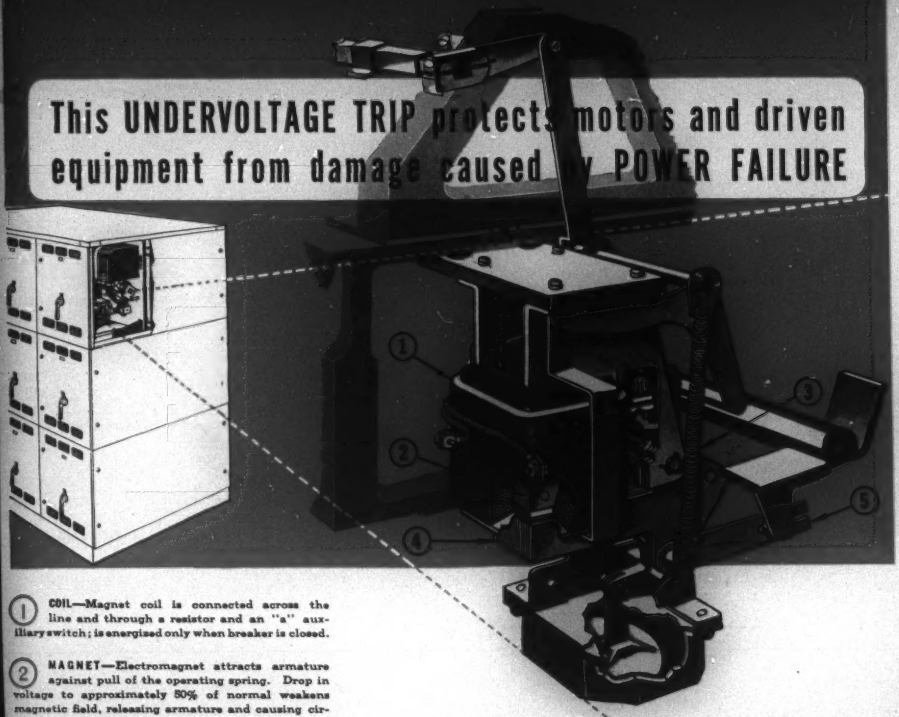
UCC

30 East 42nd Street, New York 17, N. Y.

(This advertisement has been reviewed and approved by the U. S. Navy Department)

Features of I-T-E DRAWOUT SWITCHGEAR

This UNDERVOLTAGE TRIP protects motors and driven equipment from damage caused by POWER FAILURE



(1) **COIL**—Magnet coil is connected across the line and through a resistor and an "a" auxiliary switch; is energized only when breaker is closed.

(2) **MAGNET**—Electromagnet attracts armature against pull of the operating spring. Drop in voltage to approximately 50% of normal weakens magnetic field, releasing armature and causing circuit breaker to open.

(3) **OPERATING SPRING**—When circuit breaker is open, spring holds armature against faces of magnet poles. When circuit breaker is closed a change in position of the linkage makes spring tend to pull armature away. Magnet resists this action.

(4) **ARMATURE**—Attracted by magnet against the pull of the operating spring when circuit breaker is closed. Release of armature opens breaker through link to tripper bar.

(5) **LINK TO TRIPPER BAR**—Transmits movement of armature to trip mechanism that opens breaker when pull of operating spring overcomes attraction of magnet because of undervoltage condition.

(6) **SPRING ARM LINK**—Attached to circuit breaker mechanism at upper end. Releases linkage so that operating spring holds armature against pole faces of magnet when breaker is open. When breaker is closed, it sets arm so that spring tends to pull armature away from pole faces.

Hazards arising from power failure are well known to operating men. The unexpected slowing or stopping of motor drives followed by equally unforeseen resumption of full speed can give rise to conditions damaging for d-c armatures and a-c windings, can do harm to machining and processing equipment, can injure workmen.

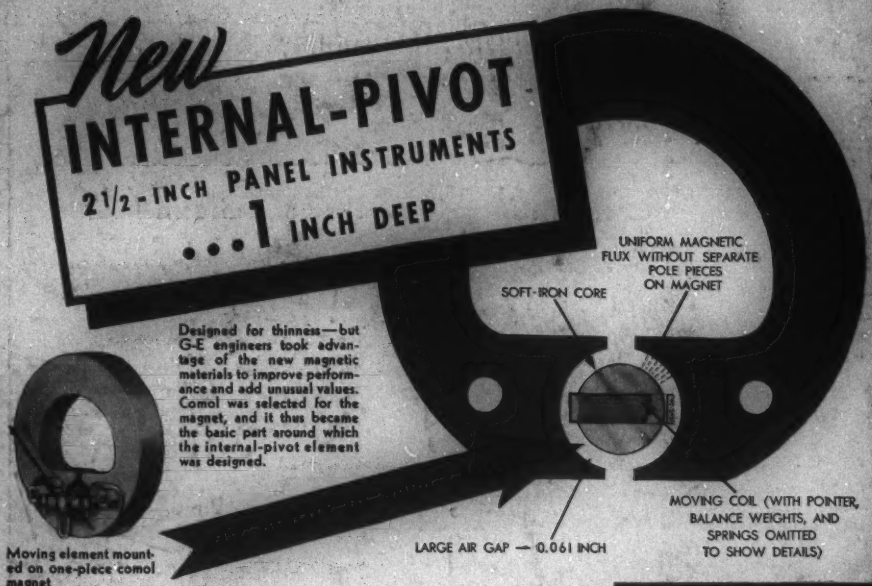
Protection against "undervoltage" is simple in principle. A drop to a predetermined, critical value causes a magnet to release an armature and the breaker opens. From that point, there need be no damaging current or unforeseen resumption of power or load.

Simple as this is, what you want on the part of the undervoltage trip is positive, dependable action. This I-T-E gives you—and we will gladly tell you about it to the last detail. Just call the nearest I-T-E representative or write to I-T-E Circuit Breaker Co., 19th and Hamilton Streets, Philadelphia 30, Pa.

Representatives in Principal Cities

I-T-E AIR SWITCHGEAR

New INTERNAL-PIVOT 2½-INCH PANEL INSTRUMENTS ...1 INCH DEEP


UNIFORM MAGNETIC FLUX WITHOUT SEPARATE POLE PIECES ON MAGNET
SOFT-IRON CORE
Designed for thinness—but G-E engineers took advantage of the new magnetic materials to improve performance and add unusual values. Comol was selected for the magnet, and it thus became the basic part around which the internal-pivot element was designed.
Moving element mounted on one-piece comol magnet
LARGE AIR GAP — 0.061 INCH
MOVING COIL (WITH POINTER, BALANCE WEIGHTS, AND SPRINGS OMITTED TO SHOW DETAILS)

Extra Values That the Comol Magnet Gives You

AN air-gap flux density of approximately 2000 gausses—made possible by the comol magnet—means a magnetic field some 50 per cent stronger than that of the conventional chrome-steel magnet.

Higher Torque This greater magnetic strength provides a substantial increase in torque. Since the weight of the moving element is about the same as that of other designs, the torque-to-weight ratio is much higher.

Faster Response The greater flux density also allows the use of a larger air gap, which minimizes any tendency toward stickiness. Faster response, which is assured by the high torque and lightweight moving system, enables accurate readings to be taken more quickly.

Improved Performance Large-radius pivots and good damping are among the other good features in the internal-pivot design—a design that packs all-round fine performance in a small space. They all add up to an instrument that is well able to withstand abnormal vibration and shock and maintain its rated accuracy.

For complete information, ask our nearest office for Bulletin GEA-4064, which covers instruments for use in radio and communications equipment; or Bulletin GEA-4117, which describes those suitable for naval aircraft. *General Electric Company, Schenectady 5, N. Y.*

Buy all the BONDS you can—and keep all you buy

GENERAL ELECTRIC

Type DW-53 d-c voltmeters, ammeters, and volt-ammeters. Designed to measure voltage and current in battery and battery-charging circuits on naval aircraft. Designed to meet all applicable Navy specifications.

For radio and other communications service: Type DW-51 d-c voltmeters, ammeters, milliammeters, microammeters; Type DW-52 radio-frequency ammeters (a-c thermocouple type). Cases are brass or molded Textolite.

HEADQUARTERS FOR ELECTRICAL MEASUREMENT